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# **Acceleration Tolerance: Effect of Exercise, Acceleration Training; Bed Rest and Weightlessness Deconditioning**

## **A Compendium of Research (1950–1996)**

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## Contents

	Page
Summary.....	iv
Introduction.....	v
Abstracts and Annotations .....	1
Additional Selected Bibliography .....	45
Author Index.....	47
Keyword Index.....	51

## **Summary**

This compendium includes abstracts and annotations of clinical observations and of more basic studies involving physiological mechanisms concerning interaction of acceleration, training and deconditioning. If the author's abstract or summary was appropriate, it was included. In other cases a more detailed annotation of the paper was prepared under the subheadings Purpose, Methods, Results, and Conclusions. Author and keyword indices are provided, plus an additional selected bibliography of related work and of those papers received after the volume was prepared for publication. This volume includes material published from 1950-1996.

## **Introduction**

The purpose of this compendium is to present summaries of clinical observations and results from more basic studies that help to elucidate physiological mechanisms for control of acceleration tolerance as affected by exercise training and deconditioning. If the author's abstract or summary was appropriate, it was utilized. In some cases a more detailed annotation was provided under the subheadings Purpose, Methods, Results, and Conclusions.

This volume includes studies published from 1950 through 1996. Author and keyword indices are provided. The material is listed in alphabetical order by first author and numbered consecutively by abstract number, not page number.

We thank our many colleagues who sent us reprints, and apologize to those whose work we have inadvertently overlooked.

The authors thank Esther Johnson for valuable technical assistance.

J.E.G.



- 1. Antonutto G, D Linnarsson, CJ Sundberg, PE diPrampero.**  
Artificial gravity in Space: vestibular tolerance assessed by human centrifuge spinning on Earth.  
*Acta Astronautica* 27:71-73. 1992.

**Authors' Abstract**

Artificial gravity created by the astronauts themselves, without any external power supply, by pedalling on a couple of counterrotating bicycles along the inner wall of the space module (Twin Bikes System, TBS), was previously suggested (Antonutto et al., 1991) to prevent musculo-skeletal decay and cardiovascular deconditioning during long term space flights. To investigate whether this unusual rotating environment would determine abnormal stimulations of the vestibular system due to Coriolis cross coupled accelerations, thus leading to acute motion sickness (AMS), the conditions of a rotating environment were reproduced in a human centrifuge. A cycloergometer was fixed to the arm of the centrifuge, the rotation speed of which was equal to that yielding 1 g at the feet level in the TBS (i.e. ranging from 19 to 21 RPM). The ergometer position was such that the combination of the horizontal and gravitational acceleration vectors was 1.414 at the inner ear level and was aligned along the head to feet axis. Three subjects, pedalling at 50 W on a cycloergometer during centrifuge's spinning, were asked to move the head following an AMS' provocation protocol. None of them developed any AMS symptoms. This supports the look of the TBS as tool for avoiding musculo-skeletal and cardiovascular deconditioning during long term space flights.

- 2. Asyamolov BF, LI Voronin, VS Panchenko, NV Ulyatovsiy, RA Bondarenko, AV Kaliberdin, SYu Elizarov, VG Plokhova, AS Yarov.**  
Effectiveness of antigravity devices of the chamberless type after 7 days of hypokinesia with head-down tilt.  
*Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina* 22:37-40, 1988.

**Authors' Abstract**

The goal of this study was to provide information for developing means to protect operators from +Gz acceleration. A total of 36 subjects, aged 20 to 31, participated in the study. All had been certified fit for centrifugation and hypokinesia with head-down tilt. Three conditions were run. In the first, 10 subjects spent 60 hours in hypokinesia with -6° head-down tilt during the night and -15° during the day. Before and after this treatment, subjects' endurance of +3Gz was assessed for 15 minutes with and without antigravity device 1 (AGD-1). In the second condition, the effectiveness of AGD-1 was tested on 24 subjects before and after a 7-day period of hypokinesia with head-down tilt (-10°). The following acceleration schedule was used: 2.5- and 3.0-G for 5 minutes each, 3.5-, 4.0- and 4.5-G for 30 minutes each. In the third condition, endurance of 6 subjects was measured before and after a 7-day period of hypokinesia using the AGD-2 device and the same acceleration schedule as in condition 2. In all cases, acceleration increased at a rate of 0.1-G per second. AGD-1 consisted of closely fitting trousers made of stretch fabric with a high elasticity modulus which could maintain the perimeter and volume of the lower body under exposure to longitudinal G-load. AGD-2 was a shortened modification of AGD-1 reaching to the knees. Operator performance was evaluated in condition 3 during exposure to acceleration with a control task using a flight instrument providing information about flight parameters. Physiological parameters were assessed by an EKG with tetrapolar chest leads, photoplethysmography of the ear, and a myogram of the femur and abdominal muscles. Subjects were all trained to criterion on the control task before centrifugation.

- 3. Balldin UI, K Myhre, PA Tesch, U Wilhelmsen, HT Andersen.**  
Isometric abdominal muscle training and G tolerance.  
*Aviation, Space, and Environmental Medicine* 56:120-124, 1985.

**Authors' Abstract**

Methods to increase G tolerance of pilots flying high performance aircraft are of vital importance. Straining maneuvers to increase G tolerance involve abdominal muscles, and high intra-abdominal pressures (IAP) are recorded during G exposure. This study was carried out to examine the effects of an 11-week abdominal muscle training program on maximal IAP, G tolerance and muscle strength/endurance in 10 fighter pilots. G tolerance was measured in a human centrifuge using simulated aerial combat maneuvers (ACM). The pilots had a higher maximal IAP before training than a control group. G tolerance, maximal IAP, and maximal peak torque of knee extensors were not changed by the training. In contrast, leg muscle endurance increased ( $p < 0.01$ ) and ratings of local perceived exertion decreased ( $p < 0.01$ ). Static endurance of the knee extensors was positively correlated ( $p < 0.05$ ) with G tolerance. It is concluded that the present abdominal training program, employed in experienced fighter pilots, is not sufficient to increase IAP or G tolerance.

**4. Balldin UI, P Kuronen, H Rusko, E. Svensson.**

Perceived exertion during submaximal G exposures before and after physical training.  
*Aviation, Space, and Environmental Medicine* 65:199-203, 1994.

**Authors' Abstract**

Ratings of perceived exertion (RPE) were registered at submaximal levels in G endurance tests of a combined strength and endurance training program in 17 pilots. After 12 months of physical training, the endurance G tolerance (time to exhaustion during simulated aerial combat maneuver), increased by a mean of 40% ( $p < 0.001$ ), while the mean RPE at 5 min submaximal G exposure decreased by 1.2 units ( $p < 0.02$ ). Following 12 months of physical training, a significant relationship was observed between the improvement of the endurance G tolerance and the decrease of the RPE at 5 min ( $p = 0.05$ ). Mean  $\text{SaO}_2$  at 5 min increased from 84 to 90% ( $p < 0.01$ ) after training, while heart rate responses to G stress did not change. It is concluded that mean RPE and, to some extent, mean  $\text{SaO}_2$

during submaximal G exposures may be used as indicators of shifts in endurance G tolerance. The procedure may reduce the need for exhaustive G tolerance tests with associated risks and discomfort.

**5. Beckman MC, KR Coburn, RM Chambers, RE DeForest, WS Augerson, VG Benson.**

Physiological changes observed in human subjects during zero G stimulation by immersion in water up to neck level.

*Aerospace Medicine* 32:1031-1041, 1961.

**Authors' Abstract**

Knowledge relative to the effects of prolonged weightlessness is needed in preparing man for space flight. The buoyant force exerted upon immersed bodies effectively simulates the weightless state with respect to proprioceptive sensory responses and perhaps in other ways. An investigation into the physiological effects of immersing subjects in water up to neck level was undertaken. It was found that water immersion produces an unnatural physiological situation in that, during respiration, the inspired air inflates the lungs to atmospheric pressure while the external pressure against the chest, abdomen, and legs, due to the water, is greater than atmospheric. This situation is equivalent to "negative pressure breathing."

A series of experiments involving seven subjects immersed in water up to neck level for periods of 5 to 23 hours (five subjects for 12 hours) showed a significant weight loss during the period of immersion, which was explained by the diuresis which occurred. Pulmonary volume measurements showed a decrease in the expiratory reserve volume and in the respiratory minute volume during immersion. There was no significant decrement in the performance of a tracking task, attributable to the water immersion, during exposure to a simulated space vehicle reentry deceleration profile. Exposure to 4.5 positive G for 15 seconds following water immersion revealed a decrement in tolerance in most subjects.

1. Immersion of subjects in water up to neck level produced a continuous diuresis



presumably on the basis of the Gauer-Henry left atrial volume receptor reflex.

2. Immersion in water up to neck level causes changes in pulmonary compartmentation represented by a slight decrease in vital capacity, decrease in the expiratory reserve volumes with an increase in the inspiratory volume, and a decrease in tidal volume which is compensated for by an increase in respiratory rate.

3. Immersion of subjects in water up to neck level for periods of 12 to 23 hours resulted in a decrease in tolerance to positive acceleration.

4. Immersion of subjects in water up to neck level for 12 hours produced a moderate change in ability to perform a tracking task during exposure to 8 G, transverse acceleration, but without significant change in physical ability to tolerate this acceleration.

**6. Bjurstedt H, G Rosenhamer, O Wigertz.**

High-G environment and responses to graded exercise.

*Journal of Applied Physiology*  
25:713-719, 1968.

**Authors' Abstract**

Ventilatory and circulatory responses to graded leg exercise on a bicycle ergometer (300, 600, and 900 kpm/min, i.e., 49, 98, and 147 W, for 6 min at each work load) were studied in eight healthy, untrained subjects in the sitting position at normal gravity (+1  $G_z$ ) and at +3  $G_z$ . The effect of increased G on the average work performed by the leg muscles was calculated to be negligible. At the highest work load, mean expired minute volume, oxygen uptake, heart rate, and arterial lactate levels for the 6<sup>th</sup> min of exercise were 19.6 liters/min, 241 ml/min, 32 beats/min, and 1.43 mM/liter higher at +3  $G_z$  than at +1  $G_z$ ; the increases were statistically significant except for arterial lactate. No electrocardiogram (ECG) abnormalities occurred at +3  $G_z$  even at the highest work load. An increase in the work load from 600 to 900 kpm/min at +3  $G_z$  caused leveling off of oxygen uptake and rise of arterial lactate in two subjects and, in another, inability to complete the work because of exhaustion. It is concluded that during leg exercise with increasing work

loads on the bicycle ergometer while in the sitting position at +3  $G_z$ , the oxygen transport to working muscles is limited primarily by disturbances in the pulmonary gas exchange; the exaggerated hydrostatic pressure differences in this condition present a greater handicap to the pulmonary than the systemic circulation.

**7. Bulbulian R.**

Physical training and +Gz tolerance reevaluted.

*Aviation, Space, and Environmental Medicine* 57:709-711, 1986.

**Author's Abstract**

The effect of physical training on +Gz tolerance is of vital interest in the aerospace community. The data on the effect of physical training on orthostatic tolerance or simulated air combat maneuvers are equivocal. The effects of aerobic and strength training programs are briefly reviewed. The data suggest a need for careful reinterpretation of research results in light of conflicting reports and methodological shortcomings. Aerobic training cannot be assumed to always be detrimental nor can strength training be assumed to be universally effective in improving +Gz tolerance. In selecting appropriate screening criteria and training regimens for aircraft personnel, it seems prudent to reinvestigate strength and endurance training effects on +Gz tolerance using multivariate research paradigms. Special attention should be directed to commonly accepted physiological principles which may vary under conditions of altered gravitation.

**8. Chase GA, C Grave, LB Rowell.**

Independence of changes in functional and performance capacities attending prolonged bed rest.

*Aerospace Medicine* 37:1232-1238, 1966.

**Authors' Abstract**

Eighteen young men were studied before and after 15 and 30 days bed rest to examine the effects of absolute bed rest and recumbent exercise during bed rest on the pulse rate response to submaximal work, cardiovascular functional capacity (max

$\dot{V}O_2$ ), physical work capacity, and orthostatic tolerance. Changes in the submaximal pulse rate as a result of the conditions of this study did not predict the trend in either work capacity or max  $\dot{V}O_2$  whereas, changes in work capacity occurred independently of changes in max  $\dot{V}O_2$  and vice versa. The highest  $\dot{V}O_2$  attainable during exercise to exhaustion on a bicycle ergometer underestimated max  $\dot{V}O_2$  4 to 23 per cent. When recumbent exercise was carried out during bed rest, the difference in the highest  $\dot{V}O_2$  attainable on a bicycle ergometer and the max  $\dot{V}O_2$  was decreased after bed rest by an increment in  $\dot{V}O_2$  during the bicycle test. Unless max  $\dot{V}O_2$  was increased during bed rest, subjects had decreased adaptability to posture afterward.

#### 9. Cherepakhin MA.

Effect of a reduced diet and hypokinesia on human tolerance to static loads.

*Kosmicheskaya Biologiya i Meditsina*  
4:67-72, 1970.

#### Author's Abstract

Three series of experiments, each 15 days in duration, were run; there were 18 subjects in the age group 24-27 years. In all the experiments the subjects were fed a ration of 1,800 Cal/day consisting of lyophilized foods. In the first series the motor activity regime was unrestricted. In the second series the subjects adhered to a rigorous bed confinement. In the third series the conditions differed from those in the second in that before and after the experiments the test subjects were exposed to accelerations in a chest-to-back direction (8 g) for a period of 120 seconds. A diet of lyophilized foods (15 days, 1,800 Cal) with a normal motor activity regime exerts no effect on man's tolerance to static loads. Hypokinesia in the form of bedrest confinement for 15 days with a diet of lyophilized foods in a quantity of 1,800 Cal/day exerts a negative effect on man's tolerance to stress. A static functional test consisting of isometric exercise can be recommended for predicting man's tolerance

to accelerations. This test can be made in small-volume chambers, in bed, in a fixed position, or in a spacesuit.

#### 10. Clark WG, IDR Gardiner, AK McIntyre, H Jorgenson.

The effect of positive acceleration on fluid loss from blood to tissue spaces in human subject on the centrifuge. *Federation Proceedings* 5:17-18, 1956.

(Abstract)

#### Authors' Abstract

As estimated by hematocrits and plasma protein determinations, fluid loss from blood to tissue spaces occurred in six seated human subjects on the centrifuge. At near blackout levels of G (3.5 to 5.0 G) maintained for 3-5 minutes, a significant loss of fluid (3.6-4.5 cc./100 cc. blood; or 216-270 cc. total) was found. The loss in four subjects exposed to 4 G for 5 minutes was reduced by anti-G suits to an average of 75% (range 28-96%) of their loss when unprotected. In two cases subjected to 3.5 G for 5 minutes, the loss was less than that of the four subjects exposed to 4.0 G for 5 minutes. In one subject submitted to 5 G for 3 minutes, the loss was less than that he obtained at 4 G for 5 minutes, although after-effects were noticed in vision. A smaller loss (132 cc. total) occurred in one of the subjects who had 30 runs of 4.7 G for 10 seconds with a 2 minute interval between runs, than occurred in the same subject after a 5 minute uninterrupted run at 4.0 G (288cc.).

At 4.0 G, the fluid losses observed were much less than those reported elsewhere for centrifuged dogs, but recovery occurred more rapidly. The losses also were less than those reported elsewhere for postural changes of humans from the recumbent to the upright positions. It is unlikely that fluid losses due to G contribute to any fatiguing effects or detrimental residual effects possibly resulting from positive acceleration experienced by test pilots or fighter pilots in combat.

#### 11. Cooper KH, S Leverett.

Physical conditioning versus +Gz tolerance.

*Aerospace Medicine* 37:462-465, 1966.

### **Authors' Abstract**

An attempt was made in this study to determine the effect of endurance training on +Gz tolerance in experienced centrifuge subjects. Eleven subjects were divided into six exercisers and five controls. For three months the exercisers engaged in a daily (5 times a week) progressive running program while the controls were asked to avoid vigorous exercise. Frequently during this period, all eleven subjects were subjected to both rapid onset and gradual onset runs on the USAF School of Aerospace Medicine centrifuge. At the conclusion of the three months, significant differences were noticed between the exercise and control groups in endurance capacity as indicated by an increase in maximal oxygen consumption. However, no significant difference was noted between the two groups in their ability to tolerate positive Gs during either gradual or rapid onset centrifuge runs.

In this study, neither an increase nor a decrease in +Gz tolerance could be correlated with endurance capacity.

### **12. Crisman RP, RR Burton.**

Physical fitness program to enhance aircrew G tolerance.

*Brooks Air Force Base, TX:*

*USAF School of Aerospace Medicine,*

*USAFSAM-SR-88-1, 1988. 50p.*

### **Authors' Abstract**

A physical fitness program of resistance training, such as weight lifting, directed toward increasing strength and anaerobic capacity will increase G-duration tolerance. This tolerance increase is particularly useful for USAF/USN pilots flying high-performance fighters during aerial combat maneuvers. A weight-training program including exercise equipment to be used by aviators to increase (and maintain this increase) their strength and anaerobic capacity is described. Aerobics conditioning with precautions and limitations for G tolerance is discussed. Figures show recommended weight-training exercises. This special report is a combined U.S. Air Force and U.S. Navy effort that came from a 1987 Joint-Service G-Tolerance Conference that was hosted by the

Naval Aerospace Medical Research Laboratory, NAS, Pensacola, FL.

### **13. Dlusskaya IG, MN Khomenko.**

Distinctions in reactions to active orthostatic and water-loading tests of subjects differing in tolerance to +Gz accelerations.

*Kosmicheskaya Biologiya i*

*Aviakosmicheskaya Meditsina*

19:22-27, 1985.

### **Authors' Abstract**

Thirty-seven healthy male test subjects, aged 19-21, with different +Gz acceleration tolerance were examined. Their blood pressure (BP) and heart rate (HR) during 5-min tilt tests and 2% water loading tests were measures 2-3 weeks prior to centrifugation. Quantitative evaluation of orthostatic tolerance using an orthostatic index and BP and HR responses to tilt tests before and after water loading revealed specific features of cardiovascular regulation in the subjects with high and low +Gz acceleration tolerance. The negative predictive indicators include: decreased BP, HR and cardiac index in the supine position in combination with high orthostatic tolerance, as well as decreased orthostatic tolerance in combination with a lower function of vasoconstrictor mechanisms in the upright position and a lower sensitivity of carotid sinus reflexes to blood volume changes during tilt and water loading tests. When examining test subjects with high +Gz tolerance, preference should be given to those who can well tolerate tilt tests and show moderately high BP and HR in the supine position, as well as to those who exhibit a noticeable increment of diastolic BP during 5-min tilt tests.

### **14. Epperson WL, RR Burton, EM Bernauer.**

The effect of physical conditioning on +Gz tolerance.

*Aerospace Medical Association*

*Preprints, 1977. p. 82-83.*

(Abstract).

### **Authors' Abstract**

New high performance aircraft are capable of developing levels of high sustained G that places increased G-tolerance

demands on pilots. It is important, therefore, that methods be found for improving G tolerance in the pilot population. Several possibilities exist; however, one of the most promising now available to the pilot is a physical conditioning program. Yet little is known about the types of physical exercises which would be best suited to increase G-tolerance. Consequently, a study was conducted to determine the influence of 2 types of physical conditioning programs on G-tolerance, as measured in 26 young men, using the centrifuge at the USAF School of Aerospace Medicine (SAM), Brooks AFB, Texas. G-tolerance was measured as the duration the subject continued the acceleration profile-called the simulated aerial combat maneuver (SACM)-until he became fatigued. During exposure to the SACM the subject wore a standard USAF anti-G garment and performed the M-1 straining maneuver as necessary to maintain vision. The SACM consisted of alternating 15 sec plateaus of +4.5 Gz and +7.0 Gz, continuing until the subject chose to halt the run-usually his point of fatigue.

**15. Epperson WL, RR Burton, EM Bernauer.**

The influence of differential physical conditioning regimens on simulated aerial combat maneuvering tolerance. *Aviation, Space, and Environmental Medicine* 53:1091-1097, 1982.

**Authors' Abstract**

The influence of physical conditioning on tolerance to a centrifugation profile called the Simulated Aerial Combat Maneuvering (SACM)--was determined using 24 young men as subjects. These subjects were assigned to groups as controls (no physical training, C), runners (R), and weight trainers (W). They followed a 2-week protocol of specified physical training. During this study, tolerance to the SACM, maximum oxygen consumption, muscle strength, and body composition were periodically determined. SACM tolerance was defined as the total time that a subject could withstand continuous exposure to a 4.5 and 7.0 +Gz centrifugation profile as determined by his voluntary endpoint of fatigue. The +Gz tolerance of the runners and controls

increased at an average rate of 4 s/week during the course of the experiment. On the other hand, the weight trainers increased their G tolerance at an average rate of 15 s/week. The difference between group W, compared with groups C and R, was statistically significant at the 5% level. Fatigue scores indicate that group W subjects take longer to reach a given level of fatigue than did the subjects of the other groups. It appears therefore that a physical conditioning program of weight training will improve human tolerance to aerial combat maneuvers.

**16. Epperson WL, RR Burton, EM Bernauer.**

The effectiveness of specific weight training regimens on simulated aerial combat maneuvering G tolerance.

*Aviation, Space, and Environmental Medicine* 56:534-539, 1985.

**Authors' Abstract**

To assess the effectiveness of muscle-strength (weight training) on simulated aerial combat maneuvering (SACM) G tolerance, seven young men were exposed to a 12-week program of whole-body weight training in which were measured strengths of various muscle groups, body circumferences, body mass, and the percentage of body fat. The magnitudes of the weights used in training were used to measure muscle strength and were compared and correlated with each subject's SACM tolerance--defined as the total time that a subject could withstand continuous exposure to a 4.5 and 7.0 +Gz centrifuge profile using fatigue as his voluntary endpoint. Chest and biceps circumferences increased 4.2% and 3.1%, respectively; abdomen and thigh circumferences did not significantly change; body fat decreased 16.8%; and body mass increased 2.3%. Abdominal (sit ups) and biceps (arm curl) strengths increased 99% and 26.2%, respectively, and were highly correlated with SACM tolerance time ( $p < 0.01$ ); leg (leg press) and chest strengths (bench press) made less significant contributions to the SACM tolerance time. A net increase in SACM tolerance times of 53% resulted from weight-training. Multiple regression analysis of all four muscle groups between weeks 1 and 12 with the SACM

tolerance had a correlation of determination of 0.61.

**17. Forster EM, JE Whinnery.**

Dynamic cardiovascular response to +Gz stress in aerobically trained individuals.

*Aviation, Space, and Environmental Medicine* 61:303-306, 1990.

**Authors' Abstract**

Very high onset sustained +Gz stress requires rapid cardiovascular response to support human tolerance. This study was conducted following a previous study concerning +Gz tolerance in aerobically trained individuals, and was initiated to determine if intense aerobic conditioning might affect cardiovascular +Gz tolerance through reduction in heart rate response to +Gz stress. The study compared heart rate response data on 22 aerobically trained runners and 13 less-conditioned individuals. All subjects were exposed to a standard medical evaluation protocol, which consisted of a gradual-onset (0.1 G/s) acceleration exposure (GOR1), followed by a series of rapid-onset (1.0 G/s) acceleration exposures (ROR), a second gradual-onset rate exposure (GOR2), and a third gradual-onset rate exposure with the subjects performing anti-G straining maneuvers (GORS). Aerobic conditioning was not found to be associated with a reduced heart rate response to +Gz stress, compared to the response of undconditioned subjects, when the following variables were considered: heart rate change from rest to maximum exposure heart rate, heart rate change from rest to the heart rate achieved at the onset of maximum G, and the rate of change in heart rate per unit +Gz. Although enhanced parasympathetic tone, induced by long-term aerobic conditioning (running) results in a reduced heart rate at rest and during +Gz stress, it does not alter the responsiveness of the heart rate to +Gz stress.

**18. Gale RR, VV Usachev, LN Gavrilova, LG Yelkina, PA Yelkin, IS Krikum, VG Ovechkin, BV Ustyushin.**

Some human reactions to prolonged centripetal accelerations [+Gz] of low intensities.

*Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina* 10:35-40, 1976.

**Authors' Abstract**

The effect of centripetal accelerations (+Gz) of low intensities (0.5-0.6 g) imparted for four days against a background of relative hypokinesia was investigated. Peripheral and intracranial circulation, equilibrium function and morphological composition of the capillary blood were examined. During the first three days of centrifuging the hemodynamic state differed insignificantly from the initial level. On the fourth day signs of cardiovascular deconditioning were found. This was indicated by the orthostatic test. Changes in the peripheral blood indicated a moderate stress reaction which persisted throughout the entire experiment. Equilibrium changes which were observed on the first day of centrifuging regressed and the post-test function did not essentially differ from the initial level. The experimental results give evidence that inertial forces can be used to lessen the unfavorable effects of hypokinesia.

**19. Georgiyevskiy VS, VM Mikhaylov.**

Effect of hypokinesia on human circulation.

*Kosmicheskaya Biologiya i Meditsina* 2:48-51, 1968.

**Authors' Abstract**

The combined effect of bedrest and accelerations on human circulation was studied using mechano- and poly-cardiographic techniques. The experiments were conducted on young healthy male test subjects. The experiments demonstrated an increase in heart rate and average blood pressure, a decrease in the ejection period and development of orthostatic hypotension. Variations in some hemodynamic indices indicated a phasic pattern reaching a maximum on the 32-42nd day.

**20. Gogolev KI.**

Correction of transcapillary exchange in man under the influence of rotation on a centrifuge while immersed in water.

*Kosmicheskaya Biologiya i  
Aviakosmicheskaya Meditsina*  
13:72-74, 1979.

**Author's Abstract**

Acceleration of +Gz induces both intravascular redistribution of fluid and shifting thereof from plasma to the perivascular space, and leads to a change in hydrocolloid balance of blood and the interstitial medium in man. Such disturbances could be the cause of changes in transcapillary exchange of fluid and proteins, the adequacy of which is determined by the functional state of mechanisms responsible for redistribution thereof in the case of sudden increase in gravity and in the aftereffect period.

In this work, we submit the results of testing the reactions of the system of hydrocolloid equilibrium in man to acceleration of 3 units +Gz after 3-day immersion, combined or not with period rotation on a small-radius centrifuge.

**21. Goldwater DJ, VA Convertino, H Sandler.**

Acceleration tolerance in 55 to 65 year old men after shuttle flight simulation.

*Aerospace Medical Association  
Preprints*, 1981. p.179-180.  
(Abstract).

**Authors' Abstract**

Healthy 55 to 65 y.o. men tolerated Shuttle re-entry acceleration before and after BR as well as subjects 35 to 55 years old. Although the G-suit improved postBR tolerance at all stress levels, it was significantly more efficacious for older men during postBR 3 Gz than for men a decade younger. These results suggest an important role for increased central blood volume in restoring postBR acceleration tolerance for older subjects. Pre BR  $\dot{V}O_2$  max, PV, estimated TBV, and height were significant independent predictors of postBR 3-Gz tolerance in these subjects. Bedrest-induced decrease in 3 Gz acceleration tolerance was directly proportional to the decrease of BV

and PV, and inversely related to prior athletic conditioning level and height. Since individuals in this age group are more susceptible to cardiac and cerebrovascular sequelae following orthostatic hypotension, use of the anti-G suit is strongly indicated during Shuttle re-entry, especially in highly aerobically conditioned individuals.

**22. Goldwater DJ, VA Convertino.**

+3Gz tolerance in aerobically-trained and sedentary men after shuttle flight simulation.

*Aviation, Space, and Environmental  
Medicine* 59:485, 1988.

**Authors' Abstract**

Thirteen men giving a history of regular aerobic training (AT) ( $\dot{V}O_2$  max  $47.4 \pm 1.6$  ml/kg.min) were compared to 8 age-matched (35 to 50 y.o) sedentary controls (S) ( $\dot{V}O_2$  max  $35.2 \pm 1.5$ ) to assess +Gz tolerance (GTOL) analogous to, although more intense than, Shuttle re-entry stress. Subjects went to greyout at +3 Gz pre-and post-6 days of head-down ( $-6^\circ$ ) bedrest (BR). PreBR GTOL for AT was 372 sec vs 537 for S (ns). PostBR decrease in GTOL was different ( $p < .05$ ) for AT: -259 sec (-68%,  $p < .01$ ) vs S: -165 sec (-35%, ns). PreBR resting (R) heart rates (HR) were lower ( $p < .05$ ) in AT (63bpm) than S (72). PostBR, resting HR of AT increased 13% ( $p < .01$ ); S HR's were unchanged. PreBR HR increase from R to peak 3 G was much larger ( $p < .05$ ) in AT (+90%,  $P < .01$ ) than in S (+63%,  $p < .01$ ). After BR, 3 Gz increased HR similarly (mean +85%,  $p < .01$ ) in both groups. Resting diastolic pressures (DBP) were lower ( $p < .05$ ) in AT (54 mmHg) than S (63) preBR as well as postBR, whereas systolic BPs were similar in both groups. After BR, deconditioned AT had + 3 Gz HR and BP responses, from rest to peak 3G, similar to S. Nevertheless, the decrease in GTOL postBR was larger in AT. PreBR plasma volume (PV, ml/kg) was inversely correlated with BR GTOL ( $r = -.64$ ,  $p < .01$ ). BR decreases in PV were correlated with low BR GTOL ( $r = .63$ ,  $p < .01$ ) and with preBR  $\dot{V}O_2$  max ( $r = .42$ ,  $p < .05$ ). Aerobic training may be associated with greater +Gz intolerance in spaceflight participants after

weightlessness exposure in the absence of countermeasures.

### 23. Golovkina OL.

External respiration and gas exchange reactions to exercise during rotation of man on a short-radius centrifuge.

*Kosmicheskaya Biologiya i*

*Aviakosmicheskaya Meditsina*

13:58-60, 1979.

#### Author's Abstract

Periodic rotation on a short-radius centrifuge (SRC) combined with physical exercise is one method of preventing functional disturbances of physiological systems, which occur under the influence of weightlessness. However, there has still been very inadequate study of the reactions of the main physiological systems of the body to rotation on an SRC combined with exercise.

Our objective here was to study the reactions of the system of external respiration and exchange of gases to rotations on an SRC ( $R = 2$  m) combined with exercise on a bicycle ergometer (BE) during prolonged immersion. Since the system of external respiration is functionally closely related to the circulatory system, we considered the possibility of using the parameters of external respiration to evaluate endurance for these factors.

### 24. Greenleaf JE, PJ Brock, D Sciaraffa.

Effect of physical training in cool and hot environments on +Gz acceleration tolerance in women.

*Aviation, Space, and Environmental Medicine* 56:9-14, 1985.

#### Authors' Abstract

Rectal temperature ( $T_{re}$ ), sweat rate, plasma volume (PV), peak oxygen uptake (peak  $\dot{V}O_2$ ), and relaxed +Gz acceleration tolerance ( $0.5\text{ G} \cdot \text{min}^{-1}$  linear to grayout) were measured in 15 healthy women 21-41 years old before and after submaximal isotonic exercise training for  $2\text{ h} \cdot \text{d}^{-1}$  on a cycle ergometer. The women had 2 weeks of acceleration runs and  $\dot{V}O_2$  testing, followed by 8 d of exercise training, post-training acceleration runs on day 9, and peak  $\dot{V}O_2$  tests on day 10. They were divided into three

groups: an exercise (heat) group, ambient temperature ( $T_a$ )  $40.6^\circ\text{C}$ , relative humidity (rh) 42%, and a peak  $\dot{V}O_2$  of 52%; an exercise (cool) group,  $T_a = 18.7^\circ\text{C}$ , rh = 48%, and  $\dot{V}O_2$  peak = 55%; and a sedentary control (cool) group. There was no change in peak ventilation, peak heart rate (HR), peak  $\dot{V}O_2$ , or in resting PV in any group after training. Heart rate and  $T_{re}$  were significantly lower after training in both cool and hot environments; HR by  $17\text{ b} \cdot \text{min}^{-1}$  ( $p < 0.05$ ) and  $27\text{ b} \cdot \text{min}^{-1}$  ( $p < 0.05$ ), respectively, and  $T_{re}$  by  $0.4^\circ\text{C}$  ( $p < 0.05$ ) and  $0.4^\circ\text{C}$  ( $p < 0.05$ ), respectively. Sweat rates were not different in any group. In all groups, acceleration tolerances were not different after training; they ranged from 3.5 to 3.8 G (373-410 s). The loss (shift) in PV during acceleration ranged from -5.8% to -10.3% (nonsignificant). With the exception of the significant reductions in HR and  $T_{re}$ , 8 d of moderately heavy physical training at 52-55% of peak oxygen uptake in cool or hot environments had no effect on slow-onset +Gz acceleration tolerance in women. These findings may be of relevance for astronauts in training.

### 25. Greenleaf JE, PJ Brock, D Sciaraffa, A Polese, R. Elizondo.

Effects of exercise-heat acclimation on fluid, electrolyte, and endocrine responses during tilt and +Gz acceleration in women and men.

*Aviation, Space, and Environmental Medicine* 56:683-689, 1985.

#### Authors' Abstract

Plasma fluid, electrolyte, protein, renin, and vasoactive hormone (epinephrine, norepinephrine, vasopressin) responses were measured in six women (21-23 yr) and four men (21-38 yr) before and immediately following an orthostatic tolerance test ( $70^\circ$  head-up tilt) and a +Gz (head-to-foot) acceleration tolerance test ( $0.5\text{ G} \cdot \text{min}^{-1}$  linear ramp to grayout). These tests were conducted before and after 12 consecutive days of exercise-heat acclimation when the subjects exercised on a cycle ergometer at a relative oxygen uptake of 44% to 49% peak oxygen uptake in a hot environment ( $T_a =$

40°C, 42% rh). During acclimation plasma volume increased by 10.6% ( $p < 0.05$ ) in the women and by 11.9% ( $p < 0.05$ ) in the men; in both groups exercise heart rate decreased significantly. After acclimation, acceleration tolerance was unchanged in both groups (range 3.1 to 3.4 G); the women's tilt tolerance was unchanged (range 33.6 to 39.5 min), but the men's tilt tolerance increased from 30.4 min before to 58.3 min ( $\Delta = 91\%$ ,  $p < 0.05$ ) after acclimation. Since the pattern of fluid, electrolyte, and protein shifts and acceleration tolerances in the women and men were virtually the same, the hormone responses were highly variable, and the men's tilt tolerance increased significantly after acclimation, it is clear that responses to tilting cannot be used to predict responses to acceleration. Analysis of data from the present study and the literature suggests that current exercise training regimes should be unrestricted for astronauts who have not previously been highly endurance trained. Until proven otherwise, care should be taken in the selection of astronauts and in the type and intensity of the exercise training programs engaged in by those who have been or are highly endurance-trained athletes.

- 26. Greenleaf JE, RF Haines, EM Bernauer, JT Morse, H Sandler, R Armbruster, L Sagan, W van Beaumont.**  
+Gz tolerance in man after 14-day bedrest periods with isometric and isotonic exercise conditioning.  
*Aviation, Space, and Environmental Medicine* 46:671-678, 1975.

#### **Authors' Abstract**

The purpose of this study was to determine the effects of isometric or isotonic exercise training on post-bedrest +Gz tolerance. Seven male volunteers, 19-22 years, underwent accelerations of +2.1 Gz (740s), +3Gz (327s), and +3.8 Gz (312s) in a selected, randomized order; the ramp to peak acceleration was 1.8 G/min. The centrifugation runs were terminated by loss of central vision (blackout) to a white light with a luminance of  $3.15 \times 10^{-5}$  log candle/cm<sup>2</sup> (0.092 ft-lambert). The study began with a 14-d ambulatory control period, followed by three 14-d bedrest periods (each

separated by a 21-d recovery period) and then a final week of recovery. During the ambulatory periods, the subjects exercised on a bicycle ergometer at 50% of their maximal oxygen uptake ( $\max \dot{V}O_2$ ) for 1 h/d. During two of the three bedrest periods, the subjects performed in the supine position one of two routines, either isometric exercise (21% of  $\max$  leg extension force for 1 min followed by 1-min rest) or isotonic exercise (68% of  $\max \dot{V}O_2$ ) for 0.5 h in the morning and afternoon. During the third bedrest period, no exercise was performed. In general, +Gz tolerance was reduced by 24% to 35% ( $p < 0.05$ ) after bedrest. Compared with control values, there were significant reductions in average tolerance times after bedrest with no exercise and isotonic exercise at all G levels. With isometric exercise, there was a significant decrease in tolerance at 2.1 Gz but not at 3.2 Gz or 3.8 Gz, even though the latter tolerances were reduced by 15.6% and by 10.0%, respectively. Both exercise regimens maintained tolerance at levels equal to or above that obtained with no exercise. Compared with control values, average tolerances were lower ( $p < 0.05$ ) after the two recovery periods between the bedrest periods (-24% to -26% at 3.2 Gz and 3.8 Gz), indicating that 3 weeks of ambulation was not sufficient time for full recovery from the deconditioning induced in this study. A prediction equation was constructed with data from all comparable studies utilizing deconditioned men riding relaxed without protective garments: Tolerance (in seconds) =  $-334 + (1715 / +Gz \text{ level})$ . From this equation, the calculated tolerance after bedrest is 13.5 min at 1.5 G, and the point of zero tolerance is 5.1 Gz.

- 27. Greenleaf JE, HO Stinnett, GL Davis, J Kollias, EM Bernauer.**  
Fluid and electrolyte shifts in women during +Gz acceleration after 15 days' bed rest.  
*Journal of Applied Physiology* 42:67-73, 1977.

#### **Authors' Abstract**

Twelve women (23-34 yr), comprising a bed-rest (BR) group of eight subjects and an ambulatory (AMB) group of four subjects, were centrifuged after 14 days of ambulatory



control (C), after 15 days of a 17-day BR period, and on the third day of recovery (R). Venous blood was taken before and after the third +3.0 G acceleration run (1.8 G/min). Relative to (C), the +Gz tolerance after BR was reduced by 49.0% ( $P < 0.05$ ) in the BR group and by 38.7% (NS) in the AMB group; during (R) the BR group regained up to 89.4% and the AMB group up to 87.1% of their (C) tolerances. In each of the three test periods, the shifts in plasma Na, Cl,  $PO_4$ , and osmotic contents, which accompanied +Gz, followed the outward shift of plasma volume (PV). The correlation of the shift of PV during acceleration with the +Gz tolerance was 0.72 ( $P < 0.01$ ). During acceleration, the PV and electrolyte loss for both groups after BR was about half the loss of (C) and (R). Compared with (C) and (R) values, potassium shifts were variable but the mean corpuscular volume and mean corpuscular Hb contents and concentrations were unchanged during all +Gz runs. The results indicate that: 1) the higher the (C) +Gz tolerance, the greater the tolerance decline due to BR; 2) relative confinement and reduced activity contribute as much to the reduction in tolerance as does the horizontal body position during BR; 3) bed-rest deconditioning has no effect on the erythrocyte volume during +3.0 Gz; and 4) about one-half the loss in tolerance after BR can be attributed to PV and electrolyte shifts.

**28. Greenleaf JE, W van Beaumont, EM Bernauer, RF Haines, H Sandler, RW Staley, HL Young, JW Yusken.**

Effects of rehydration on +Gz tolerance after 14-days' bed rest. *Aerospace Medicine* 44:715-722, 1973.

#### **Authors' Abstract**

To determine if rehydration increases +Gz tolerance following bed rest deconditioning, eight male volunteers (21-23 yrs) were subjected to acceleration levels of 2.1 G (740 sec), 3.2 G (327 sec) and 3.8 G (312 sec) presented in random order; the rate of acceleration was 1.8 G/min. Acceleration tolerance was determined by either loss of peripheral vision (greyout) or by loss of central vision (blackout) to a white light with

a luminance of  $1.2 \times 10^{-2}$  candles/cm (35.3 foot-lamberts). The experimental design consisted of a 3-week ambulatory control period (C), 2 weeks of bed rest (BR1), followed by a 2-week ambulatory recovery period (R), then 2 weeks of bed rest with rehydration prior to centrifugation (BR2) and a final week of recovery. +Gz tolerance was measured immediately before and at the end of each bed rest period. The subjects ate a calorically controlled, nutritionally balanced diet and exercised  $\frac{1}{2}$  hr each day on a bicycle ergometer at 50% of their maximal oxygen uptake (approx. 450 kcal/day) during the entire study. The subjects were rehydrated with 1.0 to 1.9 liters of a drink, containing 143 mEq/l Na, 31 mEq/l K and a total osmolality of 620 mOsm/l, given over a 3-hour period before centrifugation in BR2.

There were significant ( $p < 0.05$ ) reductions in average +Gz tolerances following both bed rest periods at all three G-levels. Compared with control values, following BR1, average ramp plus plateau tolerances decreased 36% at 2.1 G, 30% at 3.2 G and 44% at 3.8 G. Compared with recovery values, following BR2, average tolerances decreased 23% at 2.1 G, 29% at 3.2 G and 34% at 3.8 G. Rehydration increased tolerance ( $p < 0.001$ ) only at 2.1 G, but tolerance was not completely restored to control values. Compared with control values, average tolerances at all three G-levels were lower after the recovery period, suggesting that 2 weeks of recovery is not long enough to permit tolerance to return to pre-bed rest levels. After bed rest the time full visual capability can be maintained at plateau during these acceleration profiles can be estimated from the equation: Tolerance (sec) =  $345 + (1605/G\text{-level})$ . In relaxed, deconditioned men without protective garments, tolerance at 2.0 G is 7.6 min and the level of instant blackout is about 4.7 G. It is concluded that 2 weeks of bed rest results in a significant decrease in centrifugation to tolerance which occurred despite the use of moderate daily isotonic exercise. Compared to nonhydration control values, rehydration significantly improves +Gz tolerance only at 2.1 G but did not return tolerance to ambulatory control levels.

**29. Grigoriev AI.**

Correction of changes in fluid-electrolyte metabolism in manned space flights.

*Aviation, Space, and Environmental Medicine* 54:318-323, 1983.

**Author's Abstract**

In order to prevent and correct hypohydration and negative electrolyte balance, the effects of exercises, lower body negative pressure (LBNP) and water-salt supplements (WSS) were investigated in more than 100 test subjects during 14-, 49- and 182-d head-down tilt tests ( $-4^{\circ}$ ). A combined use of WSS and LBNP during regular exercises led to a distinct water and sodium retention. These changes were mainly determined by the stimulation of the renin-angiotensin-aldosterone and antidiuretic systems. After these countermeasures were tested in simulation studies, they were used by 12 cosmonauts during the 63- and 185-d space flights. The detailed analysis of the postflight examinations of the crewmembers suggests that these countermeasures may exert a beneficial effect on fluid-electrolyte balance.

**30. Grigor'yev AI, YeB Shul'zhenko.**

Effects of minimal gravitational loads on fluid-electrolyte metabolism and renal function of man during prolonged immersion.

*Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina* 13:27-31, 1979.

**Authors' Abstract**

It was demonstrated that renal excretion of fluid osmotically active substances and electrolytes could be reduced, using low gravitational exposures (+Gz). The degree and duration of water and electrolyte retention were different with respect to the experimental time. The major physiological mechanisms of the changes in fluid-electrolyte metabolism were a decrease in the glomerular filtration rate and a change in water and ion transport in renal tubules.

**31. Hoffler GW, RA Wolthuis, RL Johnson.**

Lower body negative pressure.

In: *Physiological Effects of Prolonged Positive +Gz Acceleration following One and Seven Days Bedrest*, edited by WH Shumate. Houston, TX: NASA Manned Spacecraft Center, Chapt. 6, 1971. p.111-124.

**Authors' Abstract**

1. Lower body negative pressure (LBNP) was used as a cardiovascular stressor to measure orthostatic tolerance in 9 subjects who underwent one and seven day bed rest periods.

2. Accelerative (centrifuge) +Gz tolerance testing preceded all LBNP tests except a final series run expressly to assess the possible effect of centrifugation upon LBNP responses. No correlation between the two was found.

3. Orthostatic tolerance by LBNP testing was decreased after both bed rest periods. The magnitude and extent of decrease was greater after the 7-day period of bed rest. This was best determined by elevations of heart rate and decreases in stroke volume. Resting mean pulse pressure was modestly decreased, while change in leg size tended to be variable and resting cardiac output was unaltered. Three incidents of presyncope occurred during tests after bed rest.

4. Physiologic results from LBNP tests closely parallel those of other orthostatic tests and may be used as an auxiliary test for predicting human tolerance to reentry forces.

**32. Houghton JO, DK McBride, K Hannah.**

Performance and physiological effects of acceleration-induced (+Gz) loss of consciousness.

*Aviation, Space, and Environmental Medicine* 56:956-965, 1985.

**Authors' Abstract**

Loss of consciousness (LOC) was intentionally induced by exposing eight volunteers to individually-titrated levels of head-to-foot acceleration (+Gz) using 2- and 4-s onset rates (mean = 6.1 +Gz required to induce LOC) and a gradual,  $0.067 \text{ G} \cdot \text{s}^{-1}$  onset rate (mean = 7.2 Gz required). Subjects were trained over a prior 2-week period on a multitask battery comprising three simultaneously executed tasks representative

of those required in piloting, and then centrifuged to LOC at each of the three onset rates on alternate days. Performance was assessed for 5 min prior and 7 min after each LOC. Primary results indicated: a) significant and substantial impairment in the two discrete response secondary tasks (choice reaction time and arithmetic computation), with mean recovery to pre-LOC levels within 3 min on each task, b) no group mean impairment for the primary, compensatory tracking task, c) substantial individual variation in physiologically and behaviorally defined recovery from LOC, d) a negative influence of aerobic fitness on G tolerance and LOC recoverability, and e) that recovery effects were not generally dependent upon onset rate. Mean absolute incapacitation (head dropped) for the rapid onset rates was 12.1 s. For the gradual onset rate, mean absolute incapacitation was 16.6 s. Mean relative incapacitation (head erect, no voluntary task engagement) for the rapid onset rates was 11.6 s; for the gradual onset rates, mean relative incapacitation was 15.7 s. Evidence for retrograde amnesia effects was equivocal.

**33. Jacobson LB, KH Hyatt, H Sandler.**

Effects of simulated weightlessness on responses of untrained men to +Gz acceleration.

*Journal of Applied Physiology*  
36:745-752, 1974.

**Authors' Abstract**

Space shuttle vehicle travel will expose crew and untrained lay personnel to headward-acting (+Gz) acceleration stresses which may be as high as 4 G following periods of weightlessness. Previous studies, using bed rest as an analog of weightlessness, demonstrated the orthostatic intolerance and even syncope which occurs on reexposure to a +1Gz environment (70° passive tilt) following periods of simulated weightlessness, suggesting that postbed-rest exposure to still higher +Gz acceleration stresses would exaggerate the undesirable responses. This study documents bedrest induced metabolic and physiologic changes in six untrained men exposed, following a 2-wk period of simulated weightlessness, to

possible +Gz acceleration profiles anticipated for space shuttle vehicle travel. All subjects demonstrated decreased +Gz tolerance following simulated weightlessness. While only one of six subjects could not tolerate the +Gz profile in the control phase of the study, three of the six could not complete the postbed-rest study. The use of an inflated standard Air Force cutaway G-suit improved +Gz tolerance in all subjects, but two of six subjects still failed to complete the profile. These findings are discussed in reference to the selection of untrained humans for space shuttle vehicle travel.

**34. Kakurin LI.**

Effect of long-term hypokinesia on the human body and the hypokinetic component of weightlessness.

*Kosmicheskaya Biologiya i Meditsina* 2:59-63, 1968.

**Author's Abstract**

An experimentally diminished muscular activity of man can be used as a model to reproduce some human reactions similar to those induced by weightlessness. The purpose of the 62-day experiment was to study adaptive processes of the human body and to establish the efficiency of physical exercises during hypokinesia. Detailed clinical and physiological examinations revealed disturbances in the functioning of the circulatory, respiratory and neuromuscular systems, changes in natural immunity and diuretic deterioration. Physical exercises with a load up to 1,000-1,200 Cal/day produced a limited positive effect.

**35. Kakurin LI, RM Akhrem-**

**Akhremovich, YuV**

**Vanyushina, RA Varbaronov,**

**VS Georgiyevskiy, BS**

**Katkovskiy, AR Kotovskaya,**

**NM Mukharlyamov, NYe**

**Panferova, YuT Pushkar, YuA**

**Senkevich, SF Simpura, MA**

**Cherepakhin, PG Shamrov.**

The influence of restricted muscular activity on man's endurance of physical stress, accelerations and orthostatics.

*Soviet Conference on Space Biology and Medicine* 1996. p. 110-117.

### Authors' Abstract

For the past few years the attention of Soviet and foreign researchers has been drawn to investigation of man's condition when his muscular activity is restricted (hypokinesia). The added interest in this problem is due to the fact that many of man's contemporary professions are associated with restricted muscular activity. This problem is acquiring a prominent place in astronautics since prolonged manned space flights have now become a reality.

Weightlessness and the small volume of the spacecraft cabin place man's locomotor apparatus under unusual functioning conditions. The works of Kraus and Raab (1961), Taylor et al. (1949), Deitrick et al. (1949), Graveline et al. (1961, 1964), Beckman et al. (1961) as well as of the groups headed by A.V. Korohkov, L.I. Kakurin, A.A. Demidov and other researchers have demonstrated that with prolonged restriction of movements, man develops functional disorders of the locomotor apparatus, circulatory system, neuro-endocrine system and higher nervous activity. At the present time these polymorphous disorders are combined into the syndrome of hypokinetic disease.

As applied to the problems of space medicine, hypokinesia should be investigated from two aspects. First, investigation of physiological reactions in long experiments at Earth's gravitation, and the second — prophylaxis of hypokinetic disorders that could arise in a low gravitation field and during weightlessness in space flights. It is especially important to investigate the limits of endurance of acceleration, orthostatic factors and physical stress during re-entry to Earth.

### 36. Kamenskii YuN, EB

Shul'zhenko.

Prophylaxis for disturbances of external breathing in immersion.

*Kosmicheskie Issledovaniya*  
14:474-476, 1976.

### Authors' Abstracts

A protracted stay by man in weightlessness or in conditions which simulate it is accompanied by a reduction of gravitational stability. Therefore, a search for

methods of normalization of physiological reactions after a protracted stay by man in the conditions mentioned has great significance. The study of the reactions of external breathing during "head-pelvis" overloading (+g<sub>x</sub>) by a three-unit amount after a 13-day stay by man in water immersion, and in immersion which was combined with "conditioning" gravitational effects, comprised the task of the present investigation.

The investigation has been conducted with the participation of two groups of healthy men of ages 24-36 yr. The test subjects of the first group (5 men) were situated in immersion without additional effects ("pure" immersion); the test subjects of the second group (5 men), starting from the 6<sup>th</sup> day of immersion, were subjected daily to a single effect of "head-pelvis" overloads of up to two units in amount and up to 1.5 h in duration.

Before and after immersion, the test subjects of both groups were subjected to three units of overloading for 300 sec. External breathing was investigated by the Douglas-Holdern and pneumotachography methods. We recorded and calculated the following indices: breathing frequency (BF), respiratory volume (RV), momentary respiratory volume (MRV), volume flow rate of air (intensity) at the intake (W<sub>i</sub>), the duration in inhalation (T<sub>i</sub>), the coefficients of variation of BF, RV, and T<sub>i</sub> (CV), oxygen consumption ( $\dot{V}O_2$ ), and the coefficient of oxygen use (CUO<sub>2</sub>).

The gas-exchange data have been presented in the STPD system, and the data of ventilation and the biomechanics of breathing in the BTPS system. The results have been processed statistically by a difference method.

### 37. Kamenskiy YuN, YeB

Shul'zhenko, VG Andreyeva.

Effect of systematic exposures to gravity on the external respiration function during prolonged immersion.

*Kosmicheskaya Biologiya i*  
*Aviakosmicheskaya Meditsina*  
10:40-45, 1976.

### Authors' Abstract

Test subjects were exposed to 13-day immersion alone or combined with centrifuging. The immersion did not influence the state of ventilation and gas exchange at rest, but significantly diminished the functional capabilities of external respiration. An exposure of the test subjects to acceleration during the second half of water immersion resulted in the normalization of the functional reserves of external respiration. This may be a consequence of an increase in overall physical tone of the body.

**38. Katkovskiy BS.**

Human basal metabolism during prolonged bedrest.

*Kosmicheskaya Biologiya i Meditsina* 1:67-71, 1967.

**Author's Abstract**

1. The metabolic rate and pulmonary function of healthy test subjects were studied during 20- and 62- day bedrest experiments, before and after which they were subjected to accelerations.

2. Three subjects who performed no physical exercises during the 62-day bedrest revealed a decreased metabolic rate and virtually unaltered pulmonary function.

3. Three test subjects who performed physical exercises during the experiments also manifested a reduction of oxygen consumption and metabolic rate beginning with the third 10-day period.

4. It appears very probable that the latter is unrelated to hypokinesia but is due to an increased physical conditioning or to adaptation to a changed hydrostatic pressure of body fluids.

**39. Keil LC, S Ellis.**

Plasma vasopressin and renin activity in women exposed to bed rest and +Gz acceleration.

*Journal of Applied Physiology* 40:911-914, 1976.

**Authors' Abstract**

To study the effect of prolonged recumbency on plasma vasopressin and renin activity, eight women (23-34 yr) were subjected to 17 days of absolute bed rest. The +3 Gz tolerance of the subjects was tested before and after 14 days of bed rest. From day 2 and through day 17 of bed rest,

plasma arginine vasopressin (AVP) levels were reduced by 33%. Plasma renin activity (PRA) increased by 91% ( $P < 0.05$ ) above ambulatory control values from days 10 though 15 of bed rest. When compared to precentrifuge values, exposure to +3 Gz prior to bed rest provoked a 20-fold rise ( $P < 0.05$ ) in mean plasma AVP but resulted in only a slight increase in PRA. After bed rest, acceleration increased plasma AVP 7-fold ( $P < 0.02$ ); however, the magnitude of this increase was less than the post +3 Gz value obtained prior to bed rest. After bed rest, no significant rise was noted in PRA following +3 Gz. This study demonstrates that prolonged bed rest leads to a significant rise in the PRA of female subjects, while exposure to +Gz acceleration provokes a marked rise in plasma AVP.

**40. Khapilov NV, VS Panchenko, NN Kotov, BF Asyamolov.**

Effect of hypokinesia and +Gz accelerations on transport function of human blood.

*Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina* 19:31-33, 1985.

**Authors' Abstract**

The results of 44 studies of circulation parameters and blood transport function of 14 test subjects exposed to 7-day bed rest ( $-10^0$  head-down tilt) and acceleration of 4.5 Gz have demonstrated that the blood transport carriers and their actively binding centers form working structures in the adaptive reactions. As compared to the pretest level, the distribution ratio of  $^{14}\text{C}$ -adenine between two immiscible phases (plasma/oil, erythrocytes/oil) varies from -12 to 14% on bed rest day 3 to +32 to 40% on bed rest day 7; it increases by 145-150% after exposure to +4.5 Gz acceleration. The parameters of the blood transport function give a quantitative description of its adaptive reactions to environmental effects.

**41. Khudyakova MA, YeB Shul'zhenko.**

Blood clotting function during 12-day immersion in water, and the preventive role of revolving on a centrifuge.

*Kosmicheskaya Biologiya i  
Aviakosmicheskaya Meditsina*  
3:79-81, 1977.

#### **Authors' Abstract**

There is a sparse literature dealing with hemostasis in the presence of hypodynamia. Ye. I Chazov and V.G. Ananchenko failed to demonstrate changes in 3 out of 4 subjects during 3-day hypodynamia, while one presented increased anticoagulant and lytic properties of blood. In the case of 20-day hypodynamia, the same authors found increased fibrinolytic activity of plasma and higher blood heparin content, as well as lower heparin tolerance of plasma in the 4 subjects.

According to the report of L.M. Filatova and O.D. Anashkin, an increased thrombogenic potential of blood was observed on the 8<sup>th</sup> day of bedrest in the horizontal position. Thereafter, a decrease in coagulating potential of blood was observed in the case of 64-day hypodynamia.

The results of Ye. I Dorokhova, which were obtained with 70-day hypodynamia, revealed that there was a hypocoagulation reaction toward the end of the first 2 weeks. As the period of hypodynamia increased the hemophilic reaction also increased in all subjects.

V.A. Isabayeva and T.A. Ponomareva failed to observe an increase in thrombogenic properties of blood during 10-day hypodynamia after adaptation to high altitude. Longer periods of hypodynamia (24 days) diminished coagulant properties.

Our objective here was to study the changes in various indices of hemostasis during 12-day immersion in water and to determine whether it is possible to use increased gravitation for prevention of "decondition" of the organism during immersion.

#### **42. Klein KE, F Backhausen, H Brüner, J Eichhorn, D Jovy, J Schotte, L Vogt, HM Wegmann.**

Die Abhängigkeit der Orthostase- und Beschleunigungs- toleranz von Körperbau und Leistungsfähigkeit.

(The relation between tilt table and acceleration-tolerance and their

dependence on stature and physical fitness).

*International Zeitschrift für  
Angewandte Physiologie  
einschliesslich Arbeitsphysiologie*  
26:205-226, 1968.

#### **Authors' Abstract**

Experimental studies in a group of 12 highly trained athletes ( $\dot{V}O_2$  max: 4.6 l/min) and a group of 12 untrained students ( $\dot{V}O_2$  max: 3.4 l/min) lead to the following results: 1. During a 20 min tilt (90°), which included two additional respiratory maneuvers, the number of faints and the average cardiovascular responses did not differ significantly between the groups, except for a lower heart rate level in athletes; 2. During linear increase of acceleration with a rate of 1G/15 sec, the average +Gz-tolerance (blackout level) was almost identical in both groups being 6.9 for the athletes and 6.8 for the students; 3. Statistically significant coefficients of the product-moment correlation were calculated in the total of both groups for the interrelation of the following variables: a) +Gz tolerance and arterial blood pressure at rest ( $r = +0.48$  to  $+0.55$ ), b) +Gz-tolerance and heart-eye distance ( $r = -0.41$ ), and c) total body length and responses of mean arterial pressure to tilt (in fainters:  $r = -0.11$ , in non-fainters:  $r = +0.47$ ); 4. The coefficient of multiple determination computed for the dependence of +Gz-tolerance on heart-eye distance and systolic blood pressure at rest ( $r^2_{1,23} = 0.492$ ) allows the explanation of almost 50% of the variation of +Gz-tolerance, instead of 16%, respectively 23%, if the two independent variables are used singly; 5. The maximal oxygen uptake showed the expected significant correlation to the heart rate at rest ( $r = -0.68$ ), but not to the acceleration-tolerance or to the cardiovascular responses to tilting.

#### **43. See number 42.**

**44. Klein KH, H Br ner, J Eichhorn, KL Schalk user, J Schotte, ED Voigt, HM Wegmann.**

Vergleichende Untersuchungen der k rperlichen Leistungsf higkeit des Menschen bei Muskelarbeit, im Sauerstoffmangel und bei Beschleunigung. (Evaluation of physical fitness for exercise and tolerances for hypoxia and acceleration).

*International Zeitschrift f r Angewandte Physiologie einschliesslich Arbeitsphysiologie* 22:190-206, 1966.

**Authors' abstract**

Physical fitness for exercise and tolerances to hypoxia (287 mmHg) and acceleration (+Gz) were evaluated in 20 healthy male students (21-28 years), which were physically untrained and not adapted to unusual environments. A very close correlation ( $r = +0.78$ ) was found for the true maximal oxygen uptake ( $\dot{V}O_2 \text{ max}$ ) and the aerobic capacity estimated from the heart rate during submaximal exercise using the Astrand nomogram. From some step tests only the Harvard index showed a moderate correlation ( $r = -0.35$ ) to the  $\dot{V}O_2 \text{ max}$ . The  $\dot{V}O_2 \text{ max}$  was nearly independent from hypoxia and acceleration tolerances, whereas the results of the step tests uniformly revealed negative dependances ( $r = -0.41$  to  $-0.64$ ) on the stress tolerances with the one exception of the Schneider index, which correlated positively ( $r = 0.41$ ) with the acceleration tolerance. Negative correlations ( $r = -0.46$  to  $-0.60$ ) were also computed between the different criteria for hypoxia and acceleration tolerance. "Physical efficiency" proved to be an inhomogeneous characteristic, which cannot be predestinated by "fitness" tests under exercise alone, but has to be evaluated by a test-battery combined in regard to each specific task.

**45. Klein KE, H Br ner, D Jovy, L Vogt, HM Wegmann.**

Influence of stature and physical fitness on tilt-table and acceleration tolerance.

*Aerospace Medicine* 40:293-297, 1969.

**Authors' Abstract**

A comparison of 12 healthy, but physically untrained, students with 12 highly trained athletes proved significant differences for the maximal working capacity ( $\dot{V}O_2 \text{ max}$  in students: 43.9 ml/kg/min, in athletes: 64.9 ml/kg/min). As further indication for the big differences in "physical fitness", the heart rate level of athletes was about 22 percent lower at rest and during a 90  tilt of 20 min. duration. However, "orthostatic tolerance," i.e., the number of fainters and the responses of blood and pulse pressure to tilt in non-fainters, was almost identical in both groups. The same was true for "acceleration tolerance;" i.e., the central light loss during an acceleration, increasing linearly with a rate of 1G/15sec. (in students: 6.8 +Gz, in athletes: 6.9 +Gz). In the total of both groups, statistically significant coefficients of the product-moment correlation could be computed for the interrelation of the following variables: body height and the responses of arterial pressure to tilt (for mean pressure in non-fainters:  $r = +0.47$ , for pulse pressure in fainters:  $r = -0.56$ ); +Gz tolerance and arterial pressure at rest ( $r = +0.48$  to  $+0.55$ ); +Gz tolerance and heart-eye distance ( $r = -0.41$ ). The coefficient of the "multiple correlation" computed for the dependance of the +Gz tolerance on systolic blood pressure at rest and on heart-eye distance was  $R_{1,23} = 0.70$ . By means of the corresponding equation of the multiple regression, a diagram for prediction of central light loss during acceleration from the knowledge of the two independent variables was constructed; the "standard error of estimate" was 0.56 +Gz.

**46. Klein KE, H Br ner, ED Voigt, HM Wegmann.**

Comparative studies on physiological indices of fitness in man under exercise, low pressure, and acceleration.

In: *Human Adaptability and it's Methodology*, edited by H Yoshimura, JS Weiner. Tokyo: Japanese Society for the Promotion of Science, 1966. p. 234-247.

**Authors' Abstract**

In 20 male students of one age group, which were healthy and untrained, and never had been adapted to unusual environment, physical fitness and tolerances to low pressure and acceleration were measured, and the coefficients of correlation between the results calculated. The prediction of  $\dot{V}O_2$  max. with Astrand's procedure showed a very close relationship to the true aerobic working capacity ( $r = 0.78$ ), while from all step tests, only the Harvard method correlated moderately to the same index ( $r = 0.35$ ). The true  $\dot{V}O_2$  max. was absolutely independent of the resistance either to hypoxia, or to hypergravity, but the "cardiovascular fitness" measured by step tests showed moderate to high dependency on them ( $r = 0.41-0.64$ ), which was negative in all cases, except for the relation between the "Schneider" test and the tolerance to gravitational forces, the last being likely, because of the orthostatic response in the Schneider score. The interrelation between the two stress tolerances was also negative ( $r = -0.46$  to  $-0.60$ ). Physical fitness, as determined by the different methods, is not a homogeneous quality of the body. The knowledge of the interrelations at the same time restricts and extends the meaning, significance and practical value of the indices.

**47. Klein KE, HM Wegmann, H Brüner, L Vogt.**

Physical fitness and tolerances to environmental extremes.  
*Aerospace Medicine* 40:998-1001, 1969.

**Authors' Abstract**

During "submaximum" loading tests of 20-30 min duration at simulated altitude (312 mmHg), on the tilt table, during acceleration ( $2.5 + G_z$ ), and during exercise (17 mkp/sec) at sea level and at moderate simulated altitude (578 mmHg), heart rates were significantly lower for highly trained athletes, 20-25 percent, than in non-athletes. In maximum tolerance tests, however, there was found only a significant difference between the two groups for maximum oxygen uptake at physical exercise, but no indication was seen for a positive cross-adaption effect of physical exercise training on the other stressors. Statistical analysis of the

correlation between heart rate responses to the different stressors and the corresponding tolerances proved negligible relationships only; whereas heart rates were always highly dependent on sea level  $\dot{V}O_2$  max ( $r = -0.61$  to  $-0.83$ ). The results do not support the idea of an improvement of human tolerance to environmental extremes by physical exercise training.

**48. Klein KE, HM Wegmann, P Kuklinski.**

Athletic endurance training-advantage for space flight?: The significance of physical fitness for selection and training of Spacelab crews.

*Aviation, Space, and Environmental Medicine* 48:215-222, 1977.

**Authors' Abstract**

While intensive physical exercise has been part of the conditioning of astronauts and cosmonauts for spaceflights, its benefits have been questioned. After reviewing the pertinent literature, it is concluded that the morphological and functional changes obtained with athletic endurance training are rather specific and of no general advantage for the tolerance to space stresses. Particularly during gravitational loads, in the relaxed subject, these changes allow a more pronounced shift of fluid into the lower extremities, with the possible consequence of a reduced tolerance. This unfavourable response, obviously, is accentuated through immersion and weightlessness. The aerobic work capacity is also more impaired in athletes. Based on these conclusions, recommendations for crews and passengers of future Spacelab missions are given with respect to selection and pre- and in-flight physical exercise.

**49. Kokova NI.**

Effect of fluid and salt supplements to food allowance on endurance of head-to-pelvis accelerations following 7-day 'dry' immersion and under ordinary motor activity conditions.  
*Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina* 18:33-37, 1984.

**Author's Abstract**



The effect of water-salt supplements as an agent increasing human tolerance to head-to-feet acceleration with a slow onset was examined. The test subjects were rotated in a 7.25 m centrifuge after 7-day dry immersion or normal motor activity. The water-salt supplements were given at a dose of 0.15 g NaCl and 18 ml water per kg body weight (with the total daily dose consumed in four fractions). During immersion fluid retention was significantly higher than during normal activity ( $818 \pm 139.7$  ml versus  $478 \pm 69$  ml). Water-salt supplements consumed produced a positive effect on tolerance to head-to-feet acceleration. During centrifugation after water-salt supplementation the physiological responses were less strained. Water-salt supplements taken on the last immersion day increased the tolerance level as compared to the control. The amount of the fluid retained in the body was found to be inversely proportional to the tolerance level. It is concluded that water-salt supplements may be recommended to increase tolerance to head-to-feet acceleration in aerospace medicine.

#### 50. Kotovskaya AR.

Human tolerance to acceleration after exposure to weightlessness.

*Life Sciences and Space Research*  
14:129-135, 1976.

#### Authors' Abstract

The major role in the genesis of varying human tolerance to decelerations that follow weightlessness is evidently played by hypodynamic and hydrostatic factors.

Long disuse of compensatory antigravity mechanisms in weightlessness may bring about their deconditioning and reduction of their functional capabilities, and may finally affect general tolerance of crewmembers to decelerations.

Laboratory experiments demonstrated changes in the human tolerance to Gz accelerations of varying duration (from 3 to 100 days) and tested the efficacy of different countermeasures.

A decrease in human tolerance to +Gz is on the average 2.0g. It should be noted that an elongation of simulated weightlessness (from 7 to 100 days) caused no further decrease in the +Gz tolerance.

Our investigations helped to assess the threshold of human tolerance to accelerations after an exposure to simulated weightlessness and to delineate the value of real risk. The tolerance limit to +Gz accelerations which followed simulated weightlessness of the above duration ranged from 9.5 to 13.0 g, averaging  $11.6 \pm 1.6$ g.

The information on the tolerance of Soviet and American astronauts to decelerations shown during re-entry in real space flights give support to the laboratory results and predictions.

#### 51. Kotovskaya AR, RV

Vartbaronov, SF Simpura.

Human physiological reactions during the action of transverse accelerations following hypodynamia.

*Problemy Kosmicheskoy Biologii*  
6:106-117, 1967.

#### Authors' Abstract

The physiological reactions to, and tolerance for +Gx accelerations were studied in tests on subjects following hypodynamia which lasted from 7 to 20 days.

Examinations were made of the bioelectric activity of the heart, the cerebral cortex, the function of external respiration, the arterial pressure, and the visual function. The decrease in tolerance to accelerations in all cases averaged 2 G units (range 1.2 to 4.0G), and did not depend on the duration of hypodynamia. Physiological reactions to accelerations were greater following hypodynamia. The decrease in tolerance to accelerations was caused mainly by a disorder in the regulation of the vascular tonus.

#### 52. Kotovskaya AR, RA

Vartbaronov, SF Simpura.

Change in load-factor tolerance after 70 days of hypodynamia.

*Problemy Kosmicheskoy Biologii*  
13:241-247, 1969.

#### Authors' Abstract

Stability to the action of transverse g-forces was investigated in 12 subjects before and after a prolonged (70-day) confinement to bed. Overload tolerance was evaluated in terms of the maximum g-force at which the first signs of physiological-function

disturbance made their appearance, and on the basis of shifts in the physiological reactions during and after action of the load factor. A distinct decrease in the tolerance to transversely directed g's was noted after the passive sojourn in bed. Use of drugs and physical exercises during hypodynamia was clearly helpful. The combination of prophylactic measures resulted in an increase in the maximum load factor tolerated after hypodynamia without any substantial decrease of over-all stability. In all cases, however, the physiological systems were more severely stressed under a given g-force after hypodynamia.

**53. Kotovskaya AR, RA**

**Vartbaronov, SF Simpura.**

Change in the capacity of man to withstand transverse stresses after hypodynamia of varying duration.

*Problemy Kosmicheskoy Biologii* 16:46-54, 1971.

**Authors' Abstract**

This work presents study of the capacity of 20 men to withstand transverse stresses (+Gx) after hypodynamia placed in a supine position for a length of 3 to 60 days. Gradual reduction in the resistance to the action of maximum stresses was detected at time periods of hypodynamia from 7 to 15-20 days: Later, resistance to stresses was preserved approximately at the same level up to the 60<sup>th</sup> day of hypodynamia. Similar shifts were obtained in a study of the reactivity of the cardio-vascular and breathing systems to stresses determined according to the level of pulse strain and increase of pulmonary ventilation before and after hypodynamia of varying duration. The results obtained give a basis for supposing the existence in the process of hypodynamia of two phases in reactions of an organism to stress. In the opinion of the authors, the presence of the second phase (stabilization) may support the development of a unique adaptation to conditions of hypodynamia.

**54. Krupina TN, AY a Tizul, NM**

**Boglevskaya, BP Baranova, EI**

**Matsnev, YeA Chertovskikh.**

Functional changes in the nervous system and functioning and certain

analyzers in response to the combined effect of hypokinesia and radial acceleration.

*Kosmicheskaya Biologiya i*

*Meditcina* 1:91-98, 1967.

**Authors' Abstract**

The functional state of the nervous system and some analyzers was studied using six healthy male test subjects aged 23-36 years who had been subjected to a 62-day bedrest combined with radial accelerations. Three of the subjects performed physical exercises using a bungee cord and bicycle ergometer. Prior to the bedrest experiment the test subjects were twice (at an interval of 4-6 days) exposed to transverse accelerations. Some transient neuroautonomic disturbances were observed. The most distinct disturbances were autonomic and vascular disorders and asthenization phenomena which appeared earlier and disappeared later in test subjects performing no physical exercises. Some functional changes of the acoustic and vestibular analyzers also were noted. They were related to an increase of the acoustic thresholds and decrease of the vestibulo-autonomic tolerance. The functional changes of the nervous system and some analyzers occur due to hemodynamic disturbances and afferent-efferent changes.

**55. Leach CS, PC Johnson, TB**

**Driscoll.**

Effects of bedrest and centrifugation of humans on serum thyroid function tests.

*Aerospace Medicine* 43:400-402, 1972.

**Authors' Abstract**

Changes in plasma volume and protein concentration have been reported when normal subjects are bedrested or centrifuged. Since thyroid hormones are transported by specific plasma proteins, each of these procedures could be expected to change plasma levels of these hormones. In this study centrifugation of normal healthy human subjects produced an increased concentration of total protein and albumin. When these same subjects were bedrested for six days, no change in total proteins, albumin or thyroxine binding globulin were found

although there was an eight percent decrease in plasma volume. Centrifugation and, to a lesser extent, bedrest produced changes in serum T-4 levels and the T-3 Test results. The direction of these changes (decreased % T-3 values and increased T-4 levels) indicate that these two situations produce an increased plasma concentration of thyroxine binding sites.

**56. Leach CS, J Vernikos-Danellis, JM Krauhs, H Sandler.**

Endocrine and fluid metabolism in males and females of different ages after bedrest, acceleration, and lower body negative pressure.

*Houston, TX: Johnson Space Center. NASA Technical*

*Memorandum 58270, 1985. 52p.*

**Authors' Abstract**

Space Shuttle flight simulations were conducted to determine the effects of weightlessness, lower body negative pressure (LBNP), and acceleration on fluid and electrolyte excretion and the hormones that control it. Measurements were made on male and female subjects of different ages before and after bedrest. After admission to a controlled environment, groups of 6 to 14 subjects in the age ranges 25 to 35, 35 to 45, 45 to 55, and 55 to 65 years were exposed to +3 Gz for 15 minutes (G1) and to LBNP (LBNP1) on different days. On 3 days during this pre-bedrest period, no tests were conducted. Six days of bedrest followed, and the Gz (G2) and LBNP (LBNP2) tests were run again. Hormones, electrolytes, and other parameters were measured in 24-hour urine pools throughout the experiment. During bedrest, cortisol and aldosterone excretion increased. Urine volume decreased, and specific gravity and osmolality increased. Urinary electrolytes were statistically unchanged from levels during the non-stress control period. During G2, cortisol increased significantly over its control and bedrest levels. Urine volume, sodium, and chloride were significantly lower; specific gravity and osmolality were higher during G2 than during the control period or bedrest. During LBNP2, volume was lower than during the non-stress control period, and specific gravity and osmolality

were higher than during control or bedrest periods. The retention of fluids and electrolytes after +Gz may at least partially explain decreased urine volume and increased osmolality observed during bedrest in this study. There were some statistically significant differences between the sexes and age groups. Results of the study indicated that space flight would not affect the fluid and electrolyte metabolism of females or older males any more severely than it has affected that of male or female astronauts.

**57. Lohrbauer LA, RL Wiley, SJ Shubrooks, M McCally.**

Effect of sustained muscular contraction on tolerance to +Gz acceleration.

*Journal of Applied Physiology*  
32:203-209, 1972.

**Authors' Abstract**

The increase in +Gz acceleration (the inertial force vector acting in a head-to-foot direction) tolerance afforded by static forearm muscular contraction (handgrip) was evaluated and compared with that of the standard G suit. Acceleration tolerance was assessed in eight subjects in each of four conditions for both rapid onset (1.0 G/s) and slow onset (0.1 G/s) acceleration profiles. The conditions were: 1) unprotected, 2) handgrip, 3) G suit, and 4) handgrip and G suit. The mean tolerance levels achieved for those four conditions for the rapid onset runs as defined by peripheral light loss were 3.6, 4.3, 4.8, and 5.4 G, respectively. For the slow onset runs, the tolerance levels were 4.6, 5.6, 5.8, and 6.3 G. Thus the handgrip and G-suit procedures each provided approximately 1 G of protection. Significantly, the effect of the two procedures combined proved to be additive. In the rapid onset runs, the static contraction was begun 60-90 s before the onset of acceleration and, in the slow onset runs, the contraction was begun with the onset of acceleration. The protection provided by the static concentration is, at least in part, due to the increase in mean systemic blood pressure which accompanies any such contraction. This increase prolongs the time necessary for acceleration to result in a blood pressure below intravascular pressure, this latter being

the time at which peripheral light loss occurs. Unlike during respiratory straining maneuvers, no increase in intrathoracic or intra-abdominal pressure occurred during handgrip exercise at 1 G.

- 58. Ludwig DA, VA Convertino, DJ Goldwater, H Sandler.**  
Logistic risk model for the unique effects of inherent aerobic capacity on +Gz tolerance before and after simulated weightlessness.  
*Aviation, Space, and Environmental Medicine* 58:1057-1061, 1987.

**Authors' Abstract**

Small sample size ( $n < 10$ ) and inappropriate analysis of multivariate data have hindered previous attempts to describe which physiologic and demographic variables are most important in determining how long humans can tolerate acceleration. Data from previous centrifuge studies conducted at NASA/Ames Research Center, utilizing a 7-14 d bed rest protocol to simulate weightlessness, were included in the current investigation. After review, data on 25 women and 22 men were available for analysis. Study variables included gender, age, weight, height, percent body fat, resting heart rate, mean arterial pressure,  $\dot{V}O_2$  max, and plasma volume. Since the dependent variable was time to greyout (failure), two contemporary biostatistical modeling procedures (proportional hazard and logistic discriminant function) were used to estimate risk, given a particular subject's profile. After adjusting for pre-bed-rest tolerance time, none of the profile variables remained in the risk equation for post-bed-rest tolerance greyout. However, prior to bed rest, risk of greyout could be predicted with 91% accuracy. All of the profile variables except weight, MAP, and those related to inherent aerobic capacity ( $\dot{V}O_2$  max, percent body fat, resting heart rate) entered the risk equation for pre-bed-rest greyout. A cross-validation using 24 new subjects indicated a very stable model for risk prediction, accurate within 5% of the original equation. The result for the inherent fitness variables is significant in that a consensus as to whether an increased aerobic capacity is beneficial or detrimental has not been satisfactorily

established. We conclude that tolerance to +Gz acceleration before and after simulated weightlessness is independent of inherent aerobic fitness.

- 59. Meehan JP, JP Henry, S Brunjes, H deVries.**  
Investigation to determine the effects of long-term bed rest on G-tolerance and on psychomotor performance.  
*Los Angeles, CA: University of Southern California School of Medicine. Final Report No. NAS 9-3500, August, 1965. 48p.*

**Author's Abstract**

Fourteen young men were confined to bed for 28 days. They were randomly divided into three subject groups of 5, 5 and 4 individuals. One group exercised, another did pressure breathing and the third did both. Each subject was exposed to a re-entry acceleration profile in the -Gx position while performing a three dimensional tracking task prior to the bed rest and at the conclusion of the bed rest. Tilt table tolerance and blood volumes were determined in a similar sequence.

Cardiovascular deconditioning manifested by plasma volume decrements of 20% and decreased tolerance to passive tilting resulted in all subjects and was not differentially affected by the exercise, pressure breathing or the combination maneuvers.

Performance on the tracking task during acceleration was not affected by the cardiovascular deconditioning.

- 60. Mikhaylovskiy GP, TV Benevolenskaya, TA Petrova, IYa Yakovleva, OI Boykova, MP Kuz'min, AA Savilov, SN Solov'yeva.**  
The combined effect of two-month hypokinesia and radial accelerations on the cardiovascular system.  
*Kosmicheskaya Biologiya i Meditsina* 1:86-90, 1967.

**Authors' Abstract**

Six healthy male test subjects were exposed to a 62-day bedrest and radial accelerations of the maximum tolerable magnitude. The bedrest reduced the strength of the muscular vessels, disturbed the

ophthalmic and nasal regional circulation and decreased the orthostatic tolerance of all the subjects. The latter was associated with some cardiovascular disorders and deterioration of circulatory mechanisms of adaptation to a physical load. The combined effect of bedrest and radial accelerations on the cardiovascular system was more distinct than the effect of accelerations alone. Physical exercises performed during bedrest yielded positive results.

- 61. Mikhaylorskiy GP, NN Dobronravova, MI Kozar, MM Korotayev, NI Tsiganova, VM Shilov, IYa Yakovleva.**  
Variation in overall body tolerance during a 62-day exposure to hypokinesia and acceleration.  
*Kosmicheskaya Biologiya i Meditsina* 1:66-77, 1967.

**Authors' Abstract**

The overall tolerance of the human body was studied on six healthy male subjects during a 62-day period of hypokinesia. Beginning with the third week of the experiment the protective properties of the body deteriorated considerably (quantity of blood properdin, phagocytic activity of neutrophils, lysozymic activity of the saliva and bactericidal function of the skin). In addition to inhibition of natural immunity there was development of inflammatory diseases, mostly affecting the mucous membranes and the vascular system. The results obtained should be taken into account in developing preventive measures for use during prolonged space missions.

- 62. Miller PB, SD Leverett Jr.**  
Tolerance to transverse (+Gx) and headward (+Gz) acceleration after prolonged bed rest.  
*Aerospace Medicine* 36:13-15, 1965.

**Authors' Abstract**

Tolerance to the transverse (+Gx) acceleration of a simulated Gemini re-entry profile was determined before and after 4 weeks of absolute bed rest. Tolerance to headward (+Gz) acceleration was studied before and after 4 weeks of absolute bed rest and 2 weeks of modified bed rest.

As judged by the degree of physical discomfort, the ability to respond to a central light, or the presence of electrocardiographic abnormalities, tolerance to +Gx was unaffected by 4 weeks of absolute bed rest. In each subject studied, heart rates during peak acceleration were higher after bed rest than before.

As judged by the level of acceleration at which central vision was lost, no significant change in tolerance to headward (+Gz) acceleration of rapid onset was observed after 2 weeks of modified bed rest or after 4 weeks of absolute bed rest. After each type of bed rest, the majority of the subjects had decreased tolerance to headward (+Gz) acceleration of gradual onset, but the mean decrease was not statistically significant.

Mean heart rates at equivalent levels of +Gz were significantly higher after both periods of bed rests. The only arrhythmia of clinical importance noted was the appearance of bursts of premature atrial contractions during G.O.R. +Gz in 1 subject after 2 weeks of bed rest.

- 63. Murdoch DM, LG Meyer, RP Crisman.**  
Effects of running and weight lifting on +Gz tolerance.  
*Aviation, Space, and Environmental Medicine* 59:475, 1988. (Abstract)

**Authors' Abstract**

*Introduction:*

Previous studies have shown the benefit of resistance training over aerobic training to enhance +Gz-tolerance. Aircrew members continue to enjoy aerobic exercise for recreation and health. We studied the effects of a regular aerobic training program on both the physiological benefits gained from a weight lifting program and G-tolerance.

*Methods:*

Twenty-four student naval aviators and student naval flight officers were tested for aerobic capacity, and muscular strength and endurance before and after a 10-week conditioning program. Subjects were randomly divided into two groups of weight lifting only (WL) (n = 10) and weight lifting and running (WR) (n = 13). The weight lifting program was performed 4-days per week, 2 muscular strength and 2 muscular

endurance workouts. The WR group ran a mean of 12.7 mi/week. Physical fitness assessment was accomplished both prior to and following the training program. Gradual onset rate (GOR) and simulated air combat maneuver (SACM) G-tolerance were assessed following the 10-week conditioning program.

**Results:**

No statistically significant differences were seen between the WL group and the WR group for any of the measured physical fitness parameters for either pre- or post-training. Mean post GOR tolerances for the WL and WR groups were 9.24 and 9.05 +Gz, respectively. Mean post SACM times for the WL group was 134.6 and 153.6 s for the WR group. Neither the GOR nor SACM tolerances differed significantly for the groups.

**Conclusions:**

Moderate levels of running accompanied by weight training were not detrimental to G-tolerance.

**64. Newsom BD, WL Goldenrath, WR Winter, H Sandler.**

Tolerance of females to +Gz centrifugation before and after bedrest.

*Aviation, Space, and Environmental Medicine* 48:327-331, 1977.

**Authors' Abstract**

Because women may be included as passengers in the proposed Space Shuttle System, this study was designed to investigate the +Gz tolerance of women and the possible degradation of this tolerance after a period of weightlessness as simulated by bedrest. Twelve healthy Air Force flight nurses served as test subjects. Over a 1-week period, each subject was exposed to +Gz levels starting at +2 Gz and increasing by 0.5 Gz increments to a grey-out point. This point was determined by peripheral vision loss with a standard lightbar and by reverse blood flow in the temporal artery. Ultimately, each women was subjected to three runs at the +3 Gz level; each run was approximately 55 min long, separated by 5-min rest periods. Eight subjects with the best tolerance times were selected for 14 d of bedrest in a horizontal position; the other four were ambulatory controls. Tests before

bedrest, immediately following, and 5 d later showed that average +Gz tolerance decreased by 67% after bedrest.

**65. Parnell MJ, JE Whinnery.**

The effects of long term aerobic conditioning on tolerance to +Gz stress.

*Aerospace Medical Association Preprints*, 1982. p.22-23.

(Abstract).

**Annotation**

**Purpose:**

To investigate the relationship between intense aerobic conditioning and tolerance to +Gz stress by investigating the response of marathon trained runners on the centrifuge.

**Method:**

To measure tolerance to +Gz stress, each subject rode a standard USAFSAM medical evaluation protocol on the centrifuge consisting of a gradual onset (1G/15 sec) +Gz exposure in relaxed state, a series of rapid onset (1G/sec) in a relaxed state, and a GOR exposure where subjects performed anti-G straining maneuvers.

**Results:**

There was no increase in tolerance to +Gz stress associated with intense aerobic training, and at least a low average tolerance for these subjects when compared to data in the USAFSAM acceleration repository.

Percent body fat and  $\dot{V}O_2$  max data illustrate trained subjects. Endurance training enhances cardiovascular vagal tone, evidenced by lower heart rates. Increased motion sickness including vomiting, may be evidence of enhanced vagal tone through vagal innervation of the GI tract.

**Conclusion:**

Tolerance to +Gz stress can be influenced by the type of physical conditioning HPA pilots perform. Intense aerobic training is not necessary to prepare a pilot to combat +Gz stress, and may decrease ability to perform in a high +Gz environment.

**66. Petrovykh VA, RV Kudrova, MI Kuznetsov, PP Lobzin, IG Popov, IA Romanova, YuK Syzrantsev, AM Terpilovskiy, YuF Udalov, NA Chelnokova.**

Nutritional state of human subjects kept for long periods in a horizontal position and subsequently exposed to acceleration.

*Problemy Kosmicheskoyi Biologii* 1:355-363, 1967.

#### **Annotation**

##### *Purpose:*

To study the nutritional state of a human subject kept in a horizontal position and with restricted movement.

##### *Method:*

Aspects of nutritional state of subjects during hyperdynamia and preceding exposure to overloading were carried out on 3 healthy young persons (22-24 years) for 10 and 15 days.

##### *Results:*

There was no significant difference between uropepsin levels in subjects' urine during hypodynamia and in the initial state; thus, there was no change in enzyme function of the gastric glands on feeding the experimental diet under these conditions. Negative nitrogen balance was observed in all subjects during the initial period of hypodynamia. Increase excretion of urea, ammonia, and uric acid in urine also occurred. There were no significant changes in blood cholesterol with the diet and hypodynamia. There was, however, a decrease in blood sugar due to utilization of CHO.

##### *Conclusion:*

The diet investigated proved adequate in its nutritional value and content of basic food substances for the subjects kept under hypodynamic conditions preceded by overloading, with the exception of its content of certain vitamins.

#### **67. Purakhin YuN, BN Petuknov.**

Neurological changes in healthy subjects induced by two-month hypokinesia.

*Kosmicheskaya Biologiya i Meditsina* 2:51-56, 1968.

#### **Authors' Abstract**

Six healthy male test subjects were twice exposed to acceleration followed by a 62-day bedrest during which three test subjects performed physical exercises of a known intensity. The study included tests of the

nervous system, electroencephalographic recordings, physiological tremor and fluctuations of the body center of gravity (stabilography). Results: 1. During the first two weeks of the experiment the test subjects exhibited symptoms of asthenic reactions in their behavior and nervous system. 2. Later the symptoms become more serious, acquiring the form of neurological symptoms and an asthenic syndrome (neurasthenia). 3. An analysis of data on the tremor, electroencephalogram and stabilography also indicated the development of changes in the central nervous system, autonomic nervous system and orthostatic tolerance in response to long-term hypokinesia. Functional shifts were accompanied by morphological changes in the muscular system.

#### **68. Rusko H, P Kuronen, P Tesch, U Balldin.**

Effects of aerobic and strength training on physical fitness and G-tolerance of fighter pilots.

*Aviation, Space, and Environmental Medicine* 59:474, 1988. (Abstract).

#### **Authors' Abstract**

##### *Introduction:*

Strength training has been shown to improve the G-tolerance, contrary to aerobic training. In our previous study modified endurance training was also able to increase G-tolerance of fighter pilots. This study investigated the effects of changes from aerobic to strength training and from strength to aerobic training on physical fitness and G-tolerance of fighter pilots.

##### *Methods:*

After one year of combined strength and aerobic conditioning 8 pilots started a modified endurance training (3 times a week) for 9 weeks and thereafter trained 9 weeks strength training (3-4 times a week). Another group of 8 pilots started first the 9 week strength training and thereafter the modified endurance training for 9 weeks. Physical fitness and G-tolerance was measured before the experimental period, after the first 9 week, period and after the second 9 week period.

##### *Results:*

Both groups improved significantly the maximal isometric leg extension (LEF) and

trunk extension (TEF) forces, as well as G-tolerance, significantly during the first 9 week period. In addition, strength training improved the maximal isometric trunk flexion force (TFF) significantly. During the second 9 week period the modified endurance training decreased significantly LEF, TFF and G-tolerance. The strength training improved further TFF while the changes in TEF, LEF and G-tolerance were insignificant.

**Conclusions:**

G-tolerance and muscular force are decreased if endurance training is started after strength training period.

**69. Rusko H, P Kuronen, P Tesch, U Balldin.**

Relationship between G-tolerance and physical fitness of fighter pilots.

*Aviation, Space, and Environmental Medicine* 60:512, 1989. (Abstract).

**Authors' Abstract**

**Introduction:**

Strength training has been shown to increase the g-tolerance in fighter pilots, contrary to aerobic training. During a M-1 maneuver the pilots are supposed to activate both abdominal and leg musculature. This study investigated the correlations between g-tolerance and variables related to the strength and endurance of the fighter pilots.

**Methods:**

The pilots (n = 19) were studied twice with 6 months' interval. G-tolerance was measured with repeated 15 s periods at 3.5 and 5.5 G without anti-G-suit until exhaustion.

**Results:**

In the first measurement of isometric leg extension (LEF,  $r = .46$ ,  $p < 0.05$ ), trunk flexion (TFF,  $r = .59$ ,  $p < 0.01$ ) and trunk extension (TEF,  $r = .57$ ,  $p < 0.01$ ) forces as well as jumping height (JUHE,  $r = .78$ ,  $p < 0.001$ ) correlated significantly with G-tolerance. Maximal oxygen uptake ( $r = .63$ ,  $p < 0.001$ ) and maximal blood lactate concentration ( $r = .57$ ,  $p < 0.01$ ) after treadmill running test to exhaustion also correlated highly significantly with G-tolerance. In the second measurement only TFF ( $r = .48$ ,  $p < 0.05$ ) and TEF ( $r = .49$ ,  $p < 0.05$ ) demonstrated significant correlations

with G-tolerance. When the two measurements were combined (n = 38) TFF, TEF and JUHE were found to correlate significantly with G-tolerance ( $p < 0.01$ ).

**Conclusions:**

Although a good overall fitness seems to be necessary for the pilot, the abdominal and back muscle strength are the most indicative characteristics.

**70. Sandler H, D Goldwater, SA Rositano.**

Physiologic response of male subjects ages 46 to 55 years to Shuttle flight simulation.

*Aerospace Medical Association*

*Preprints*, 1979. p.43-44. (Abstract).

**Authors' Abstract**

The present study was conducted on seven untrained older male subjects (ages 46 to 55) to assess the magnitude of physiological changes occurring during a ground-based simulation of Shuttle flight. In addition, G-suit effectiveness was evaluated as a countermeasure for the expected cardiovascular deconditioning occurring with bed rest (10 ½ days) since it is anticipated that antigravity suits will be used or provided for use during future Shuttle missions. On the seventh day of BR, each subject received +1.5 Gz with a G-suit and without a G-suit. On the following day, the subjects underwent +2 Gz with and without a G-suit. On the ninth day, the subjects received +3 Gz with and without a G-suit. Blood pressure and heart rate were monitored. All parameters increased significantly during acceleration both before and after BR. G-suit usage before and after BR resulted in significantly lower heart rate at +1.5 Gz and +2 Gz and higher systolic and diastolic blood pressures at all three G levels. In conclusion, older individuals have some degree of protection during Gz, probably due to loss of vascular elasticity with the aging process.

**71. Sandler H, P Webb, J Annis, N Pace, BW Grunbaum, D Dolkas, B Newsom.**

Evaluation of a reverse gradient garment for prevention of bed-rest deconditioning.



*Aviation, Space, and Environmental Medicine* 54:191-201, 1983.

**Authors' Abstract**

A reverse gradient garment (RGG) was used to intermittently induce venous pooling in the extremities of a magnitude similar to that seen in going from a lying to standing position during the course of a 15-d period of horizontal bed rest. Venous pooling failed to improve bed-rest-induced losses in +2.5 Gz and +3.0 Gz centrifugation tolerance or to prevent increased heart-rate responses to lower-body negative pressure (LBNP). Four subjects served as controls, four were treated. Tests during the 7-day recovery period showed fluid/electrolyte and body composition values to have returned to pre-bed-rest levels with continued depression of acceleration tolerance times (56% decreased at +2.5 Gz and 74% decreased at +3.0 Gz compared to pre-bed-rest levels) and exaggerated blood insulin response on glucose tolerance testing (blood insulin for treated group increased 95% at 1 h before bed rest and 465% during recovery). This study demonstrates that the physiologic changes after bed rest persist for significant periods of time. Acceleration tolerance time proved to be a sensitive test for the deconditioning process.

- 72. Shulzhenko EB, IF Vil-Vilyams, EA Aleksandrova, KI Gogolev.**  
Prophylactic effects of intermittent acceleration against physiological deconditioning in simulated weightlessness.

*Life Sciences and Space Research* 17:187-192, 1979.

**Authors' Abstract**

The prophylactic effect on adult human males of intermittent acceleration against physiological deconditioning in weightlessness simulated by water immersion was studied at +0.8, +1.2, and +1.6g. These prophylactic exposures reduced renal excretion of fluid and plasma volume changes, and increased venous compliance and the time at which the subjects could tolerate an acceleration field of +3 g.

- 73. Shulzhenko EB, IF Vil-Vilyams, MA Khudyakova, AI Grigoryev.**

Deconditioning during prolonged immersion and possible countermeasures.

*Life Sciences and Space Research* 14:289-294, 1976.

**Authors' Abstract**

Test subjects, covered with a waterproof highly elastic cloth, were exposed to 13-day water immersion up to the neck. They were divided into two groups. The first (control) group consisting of six persons was exposed to immersion alone and the second (experimental) group was exposed daily to accelerations of 0.6-2 Gz for 60-90 min during the last 6 days of immersion. Before and after immersion all the test subjects were exposed to +3 Gz for 5 min which served as a provocative test. These experiments give evidence that the use of dry immersion allows experimentation during prolonged immersion without concomitant complications. Variations in the physiological parameters (cardiovascular system, fluid-electrolyte balance, blood-coagulatory system) are indicative of the preventive effect of periodic accelerations during 13-day immersion.

- 74. Shul'zhenko YeB, VG Kozlova, KA Kudrin, AS Yarov, VG Plokhova.**

G suit of bladderless type as a means of improving orthostatic stability after water immersion hypokinesia and exposure to accelerations.

*Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina* 17:30-33, 1983.

**Authors' Abstract**

Orthostatic tolerance after 7-day dry immersion and head-to-feet acceleration was investigated on test subjects with and without an antigravity suit of bladderless type. With the suit on, the 20 min tilt test at 70° prior to immersion induced less marked changes than without the suit. When the suit was on, cardiovascular reactions to tilt tests after immersion and acceleration improved. The maximum heart rate decreased from 135 ± 4 to 101 ± 5 beats/min ( $p < 0.01$ ), minimum stroke volume increased from 29 ± 2 to 41 ±

3 ml ( $p < 0.05$ ) and pulse pressure grew. Thus, an antigravity suit may help increase initial orthostatic tolerance and maintain it after the combined effect of simulated hypogravity and acceleration.

#### **75. Spence DW.**

Abdominal muscle conditioning as a means of increasing tolerance to +Gz stress.

*Aerospace Medical Association Preprints*, 1981. p.148-149. (Abstract).

#### **Annotation**

##### *Purpose:*

To determine the effects of specific abdominal muscle conditioning on +Gz tolerance.

##### *Method:*

Twenty male volunteers (18-38 yrs) were randomly assigned to two groups after completing baseline measurements of anthropometry, body composition, muscular strength and endurance (MVTC), G-tolerance and heart rate response to G stress. Group 1 consisted of the abdominal muscle conditioning (AMC) subjects, which followed an AMC program 3 times per week for 12 weeks (36 workouts). Group 2 consisted of the control subjects (C) who did no abdominal conditioning.

During the 12 week experimental period both groups underwent a centrifugation profile of alternating 15 second plateaus at 4.5 and 7.0 +Gz until fatigue or visual loss criteria were met (100% peripheral or 50% central light loss). The centrifuge protocol for both groups was followed weekly for four weeks then bi-weekly for eight weeks. Determinations of abdominal muscle strength and endurance were made on the AMC group four times during the experimental period. Baseline measurements were performed again at the end.

##### *Results:*

1) Muscular strength and endurance to increased significantly ( $p < 0.01$ ) during the conditioning program up to a maximum of 177%.

2) However, further centrifuge training adaptation had occurred which was not significantly affected by the muscle conditioning program as evidenced by the

lack of statistically different tolerance between the groups.

##### *Conclusion.*

The lack of statistical significance between groups or trials on heart rate response to an equal G stress supports the finding that abdominal muscle conditioning did not increase G-tolerance.

#### **76. Suvorov PM.**

Influence of thirty-day hypokinesia in combination with exposure to LBNP on tolerance to accelerations (+Gz).

*Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina* 8:65-68, 1971.

#### **Author's Abstract**

A study was made of the effect of hypokinesia combined with LBNP on tolerance to accelerations. Before and after hypokinesia the subjects were centrifuged at 3 g for 30 sec and at 5 g as long as it could be tolerated. Two days after exposure to hypokinesia and LBNP the duration of tolerance to accelerations of 5 g was 24.2-36.5% of the initial level. This may be brought about by the functional activity of the muscular system and venous tone which results in a marked decrease in systolic volume and cardiac output during exposure to accelerations and accordingly in the early development of optic disturbances.

#### **77. Tesch PA, H Hjort, UI Balldin.**

Effects of strength training on G tolerance.

*Aviation, Space, and Environmental Medicine* 54:691-695, 1983.

#### **Authors' Abstract**

The G tolerance of pilots flying modern, high-performance fighter aircraft is crucial. Therefore, methods to increase G tolerance are of vital importance. In this study, G tolerance was studied in a human centrifuge using simulated aerial combat maneuvers (ACM)--consisting of 15-s periods of 4.5 and 7 G until exhaustion--before and after 11 weeks of muscle strength training. The ACM-time in 11 fighter pilots was increased after this training by 39%. Gains were observed in knee extensor muscle strength during slow contractions by 17% and in anaerobic power by 14%. Aerobic

performance and various muscle histochemical indices, as assessed from muscle biopsy samples obtained from m. vastus lateralis, were unchanged. Neuromuscular adaptation seems to be responsible for the increased muscle strength, as well as for the improved performance of the M-1 straining maneuver. This might explain the enhanced G tolerance.

**78. van Beaumont W, JE Greenleaf, HL Young, L Juhos.**

Plasma volume and blood constituent shifts during +Gz acceleration after bedrest with exercise conditioning. *Aerospace Medicine* 45:425-430, 1974.

**Authors' Abstract**

The purpose of the present study was to investigate the influence of isometric and isotonic exercise during bedrest on plasma volume (PV) and blood constituents during +Gz acceleration in seven young men. During bedrest, PV decreased between 8.0% and 11.5%. During centrifugation before bedrest, the average decrease in PV was between 10.7% and 13.2%, with concomitant plasma protein losses of 2.6% to 3.7%, and albumin losses of 1.2% to 4.6%; after bedrest, the corresponding changes with centrifugation were between -6.3% to -7.1%, -1.1% to -2.0%, and +2.4% to -3.1%, respectively. The average acceleration tolerance during pre-bedrest control runs was  $1,129 \pm SE 27$  s, while after bedrest, the mean tolerance was  $817 \pm SE 31$  s ( $p < 0.05$ ). For comparative purposes, additional hematological changes with centrifugation were evaluated from nine different hypovolemic, ambulatory subjects. During +Gz acceleration there was an isotonic loss of plasma fluid (8.6% to 11.2%) with respect to serum sodium, potassium, chloride, creatinine, and osmolarity; however, serum glucose concentration increased between 6.3% and 19.3%. It is concluded that during acceleration (a) the mean reduction in PV and protein contents after bedrest is about half as great as during the control runs before bedrest; (b) isometric and isotonic exercise during bedrest have no effect on the decrease in PV and protein contents during centrifugation; (c) during +Gz acceleration, in

hypohydrated ambulatory subjects, there is an isotonic loss of plasma fluid; (d) centrifugation tolerance was significantly reduced following bedrest; and (e) the two exercise regimens had no statistically significant effect upon post-bedrest centrifugation tolerance; however, both isometric and isotonic exercise reduced the average +Gz tolerance decrement by 85-100s.

**79. Vil-Vilyams IF.**

Principle approaches to selection of the short-arm centrifuge regimens for extended space flight.

*Acta Astronautica* 33:221-229, 1994.

**Author's Abstract**

Eight +Gz regimens on the SAC varying in their values (within 0.8 to 1.6 G), exposures, schedules, etc. were analyzed. Some regimens were combined with water-salt supplements (WSS) or veloergometer training (VE). Weightlessness was simulated by 3- to 28-day water immersion. +3 Gz loads on the centrifuge with the radius of 7.5m were applied prior to and post immersion. Regimens for human runs on the SAC as a novel, perspective countermeasure for interplanetary expeditions should be selected with due regard of the human tolerance, their efficiency, and subsequent verification and specification in orbital flights. These approaches showed that 3 days of exposure to 1.2 G combined with WSS and 6 days of exposure to G-loads from 0.8 to 1.6 G together with VE were most optimal.

**80. Vil-Vilyams IF, YeB**

**Shul'zhenko.**

Cardiac arrhythmia following postimmersion +Gz accelerations.

*Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina* 12:50-56, 1978.

**Authors' Abstract**

Cardiac arrhythmia is a common disorder occurring under the influence of altered gravity. Thus, under the influence of accelerations, extrasystolic arrhythmia, sinus arrhythmia and relative bradycardia are the most typical forms of rhythm disturbances

due to accelerations. Under weightless conditions, spacecraft crews not uncommonly developed rhythm disorders in the form of isolated and systemic extrasystoles.

Immersion is one of the ground-based models of weightlessness. However, there has been little study of arrhythmias occurring under the influence of immersion followed by exposure to accelerations. We only know that, in one study dealing with human subjects, an attack of paroxysmal tachycardia developed in a subject 23 h after dropping into the immersion medium. Post-immersion functional load tests revealed more marked sinus tachycardia than in control studies.

Our objective here was to investigate the effect of immersion followed by head-pelvis accelerations on distinctions of development of cardiac arrhythmia.

**81. Vil-Vilyams IF, YeB Shul'zhenko.**

Functional state of the cardiovascular system under the combined effect of 28-day immersion, rotation on a short-arm centrifuge and exercise on a bicycle ergometer.

*Kosmicheskaya Biologiya i  
Aviakosmicheskaya Meditsina*  
14:42-45, 1980.

**Authors' Abstract**

The cardiovascular function of four test subjects exposed to 28-day "dry" immersion was examined before and after 6-day cycles of rotation in a short-arm centrifuge to provide 1-2 Gz, bicycle ergometer exercise, and their combination. An exposure to acceleration of 3 Gz in a 7.25 m arm centrifuge was used as a provocative test. The above countermeasures reduced but not eliminated entirely immersion-induced cardiovascular deconditioning. From this study a combined use of acceleration of 1-2 Gz in a short-arm centrifuge and bicycle ergometer exercise can be recommended as a countermeasure against cardiovascular deconditioning in weightlessness.

**82. Wessel JA.**

An investigation of the relation between man's fitness for strenuous

work and his ability to withstand high headward acceleration.

*University of Southern California,  
Los Angeles, CA: Ph.D.*

*Dissertation, 1950. 109p.*

**Author's Abstract**

1. An investigation was made of the relationship between fitness for strenuous work and G-tolerance in twenty-three healthy male university students.

2. The study was designed to determine the relationship between the subjects' tolerance to +5 G and their fitness for strenuous work; to study the effects of a training program on the subjects' G-tolerance; and to investigate the influence of cessation of systematic training on G-tolerance.

3. Fitness for strenuous work was measured by means of performance tests, namely, the Harvard Step and Army Air Force Tests and the hand dynamometer strength test.

4. Each subject was exposed to +5 G until he greyed out or for a maximum run of 30 seconds. G-tolerance was measured in terms of earopacity during acceleration and during an 8 minute recovery period, and pulse rates during an 8 minute recovery period after acceleration for those subjects who endured +5 G for 30 seconds; and time until grey-out for those subjects who greyed out at +5 G.

5. The basic exercises used in the six and a half weeks' training program were weight training and running. These items were selected because of their high components of muscular strength and cardiovascular endurance. Each subject participated at least three times weekly in the training program.

6. During the eight weeks' period after training had ended, the subjects were requested to participate as little as possible in organized physical activity.

7. Analysis of the fitness measures revealed that most of the subjects were in "average" physical condition when they started the training program. The level was raised to "good" after training and dropped somewhat eight weeks after the program stopped.

8. A statistically significant increase in the Harvard Step Test scores, Army Air Force

Test scores and hand dynamometer strength was found after a six and a half weeks' of the systematic training program.

9. G-tolerance measures showed a significant improvement after the six and a half weeks' of the systematic training program.

10. A slight but consistent relationship was found to exist between G-tolerance (earopacity at the end of the run and pulse rates immediately after +5 G) and fitness for strenuous work as measured by the Harvard Step and Army Air Force Tests.

11. A statistically significant drop-off in fitness as measured by the Army Air Force Test was found eight weeks after systematic training had stopped. Only a slight drop-off in fitness was observed as measured by the Harvard Step Test and hand dynamometer strength test.

12. A statistically significant drop-off in G-tolerance measures (earopacity and pulse rates) for those subjects who endured a +5 G for 30 seconds was noted eight weeks after the training program stopped. Group performance on the +5 G-test runs showed no change in duration of the centrifuge runs.

### **83. Whinnery JE.**

+Gz tolerance correlation with clinical parameters.

*Aviation, Space, and Environmental Medicine* 50:736-741, 1979.

#### **Author's Abstract**

Increased +Gz stress demands continue to be placed on modern high-performance fighter aircraft pilots. Precise definition of normal +Gz tolerance along with a full understanding of the physiologic and anatomic factors that influence +Gz tolerance is therefore of increasing importance. If certain subtle medical abnormalities are associated with altered +Gz tolerance, it will be necessary for medical standards to recognize them and to find in what way they affect +Gz tolerance. With the cost of fighter aircraft becoming tremendously high, along with the associated high cost of training aviators to fly them, it will become more important to assure safety by selecting only those individuals most suited to tolerate the multistress environment of the fighter aircraft. If certain parameters are associated

with increased +Gz tolerance, it might be necessary in the future to establish high-performance fighter aircraft selection standards so that a group of aviators with super-high +Gz tolerance could be selected to maintain complete air superiority. Initial studies measuring the +Gz tolerance of 59 USAF aircrewmembers undergoing aeromedical evaluation were made on the USAF School of Aerospace Medicine human centrifuge. Specific clinically measurable parameters were found to be associated with +Gz tolerance. A high +Gz tolerance prototype is described. The parameters associated with high +Gz tolerance are not necessarily the optimum attributes for the high-performance fighter pilot since these parameters do carry increased risk for cardiovascular disease.

### **84. Whinnery JE, MJ Parnell.**

The effects of long-term aerobic conditioning on +Gz tolerance.

*Aviation, Space, and Environmental Medicine* 58:199-204, 1987.

#### **Authors' Abstract**

Aerobic conditioning programs for aircrews of high performance fighter type aircraft are very important in assuring optimum fitness and health. The aerobic conditioning resulting from running alters the physiologic state of the individual, and whether or not this alteration affects +Gz tolerance is unknown. In this study, 27 long-term (2 years of running) aerobically conditioned subjects were tested for gradual ( $1\text{ G} \cdot 15\text{ s}^{-1}$ ) and rapid onset ( $1\text{ G} \cdot \text{s}^{-1}$ ) +Gz tolerance. Maximum  $\dot{V}\text{O}_2$  and percent body fat measurements were also performed and correlated to the +Gz-tolerance measurements. Although beneficial for optimum health and fitness, increased aerobic condition ( $\dot{V}\text{O}_{2\text{max}}$ ) resulting from long-term running was not found to enhance +Gz tolerance. No relationship was observed between aerobic condition and +Gz tolerance. An increased susceptibility to motion sickness was found to be associated with long-term aerobic conditioning. Certain individuals were found to be predisposed to cardiac rate and rhythm disturbances (A-V dissociation and transient asystole) which could potentially alter +Gz-tolerance. Optimum physical conditioning programs for

aircrew of fighter aircraft have yet to be determined and implemented. Specificity of exercise training and assurance of the absence of exaggerated cardiovascular response to +Gz stress resulting from physiologic alteration of autonomic tone are critical to the design of optimum conditioning programs for fighter aircraft aircrews.

**85. White PD, JW Nyberg, LM Finney, WJ White.**

Influence of periodic centrifugation on cardiovascular function of man during bed rest.

*Santa Monica, CA: Douglas Aircraft Co. Inc., Report No. DAC-59286, 1966. 47p.*

**Authors' Abstract**

A study was made of the influence of periodic centrifugation on the physiological disturbances associated with 10 days of bed rest. During bed rest the subjects were scheduled to ride the centrifuge 4 times each day; the duration of each ride was 20 min; and the magnitude of acceleration was +2.5 g<sub>z</sub> at heart level. Subjects exercised for a 14-day period before the study. The energy cost of this exercise was approximately 1,000 kcal/day/man.

Functional and diagnostic tests conducted at regular intervals during the experiment revealed the following:

1. The prescribed regimen of +2.5 g<sub>z</sub> for 20 min exceeded tolerance to positive acceleration. The modal conditioning regimen was +1.75 g<sub>z</sub> for 20 min 4 times each day. When the magnitude of acceleration is referenced to foot level, the integrated g-time is 4.7 g-hours.

2. Expected deterioration produced by recumbency in the ability to tolerate 70° head-up tilt for 20 min was largely alleviated by periodic centrifugation, as judged by syncopal episodes and highest orthostatic heart rates.

3. The conditioning regimen did not appear so effective as shorter g-time integrals, as judged by highest orthostatic heart rates and plasma volumes.

4. Step-function acceleration tolerance and tolerance for sustained acceleration are more sensitive than the standard bioassay

method for measuring cardiovascular changes at bed rest.

5. Tolerance to positive acceleration declines during the first 12 hours of bed rest, remains relatively constant during bed rest, and improves during ambulation.

6. Losses in body weight were progressive and ranged from 0.98 to 2.35 kg. Average weight loss during the 10-day period was 2%.

7. The condition of the experiment resulted in an average loss of 17% in total blood volume, 26% in plasma volume, and 2% in red blood cell volume.

8. No significant changes were seen in serum electrolytes, bilirubin, glucose, or blood urea nitrogen; in red blood cell, white blood cell, or reticulocyte counts; in hemoglobin, hematocrit, or in mean corpuscular hemoglobin concentration; in hearing, or in the postural equilibrium; nor was there any change in exercise tolerance as measured by the Master's two-step test.

9. No cardiac irregularities or arrhythmias were encountered in the testing of eight subjects during a total of 135 hours of positive acceleration.

10. Application of negative pressure to the lower half of the body produces cardiovascular changes similar to those seen in 70° head-up tilt. Application of a pressure differential of 70 mmHg to subjects after 10 days of bed rest produced presyncopal symptoms in 2 to 4 min. During the prerenumbency period, these two subjects tolerated 20 min of negative pressure without symptoms.

**86. White PD, JW Nyberg, LM Finney, WJ White.**

A comparative study of the physiological effects of immersion and bed rest.

*Santa Monica, CA: Douglas Aircraft Company Inc., Report No. DAC-59226, 1996. 77p.*

**Authors' Abstract**

The purpose of the study was to compare the physiological responses of 10 subjects, each serving as his own control, during alternate 10-day periods of immersion and bed rest. Functional, diagnostic, and monitoring tests conducted before, during,

and after the 10-day testing periods were used to follow physiological changes produced by these two analogs of null gravity and to quantitatively compare their effects. Fluid silicone was used as the immersion medium.

Neither immersion nor bed rest produced appreciable changes in Master's two-step test of exercise tolerance, resting oxygen consumption, tolerance to acceleration in the  $g_z$  direction, visual and auditory acuity, or in ECG and heart sound recorded during tilt-table testing. There were no significant changes in microscopic or qualitative analysis of the urine for sugar, acetone, or protein; resting blood pressure, temperature, heart, and respiration rate; blood and urine chemistries or kidney and liver functions.

No serious complications were noted in any of the subjects during immersion or bed rest. Neither analog produced a free-water diuresis. The results of the study confirm the detrimental effects of prolonged immersion and bed rest on orthostatic tolerance and extracellular fluid volume. Both analogs brought about a deterioration in the mechanisms essential for adequate circulation in the erect position. This was shown by increased incidence of presyncopal reactions, by declines in pulse pressure, and by increased heart rate during tilt-table testing. Experimental conditions produced reductions in plasma, blood, and extracellular fluid volumes; declines in maximum oxygen consumption; and some impairment of postural equilibrium. Losses in body weight were progressive, the average was approximately 2% of initial weight. A negative free-water clearance was obtained in all subjects during immersion and bed rest.

Differential effect of the two environments are seen in orthostatic tolerance, fluid compartments, and renal function. The incidence of pre-syncopal reactions was higher and occurred earlier during immersion than during bed rest. Heart rates were higher and pulse pressures were lower during immersion than during bed rest. After 5 days of immersion and bed rest, the extracellular fluid decreased by 3% and 2%, respectively. After 10 days, the net decrease in fluid was 5% during immersion and 7% during bed rest. The conditions of immersion produced a larger loss in plasma

volume after 5 days than did bed rest, but the net loss after 10 days was approximately the same for both environments. Changes in blood volume were parallel to those of plasma volume. Immersion produced an elevated urine flow, as evidenced by a comparison of urine outputs in the two environments and by higher urine outputs than fluid intakes during immersion. During bed rest the subjects produced a more concentrated urine, both with respect to individual electrolytes and solute load. During immersion the daily solute load excreted by the kidney was higher, urine output was larger, and osmolar clearance was higher.

The silicone fluid, immersion tanks, filtration, and cooling equipment met the requirements of the experiment. Except for two subjects, skin problems that developed during immersion were trivial. An effort to relate the occurrence of skin problems to bacteria, water, and contamination of the silicone was inconclusive. During a 6-month period following the study, the subjects were free of abnormal physical signs, symptoms, and skin problems.

#### **87. White PD, JW Nyberg, WJ White.**

A comparative study of the physiological effects of immersion and recumbency.

In: *Proceedings of the Second Annual Biomedical Research Conference. Houston, TX: NASA, Manned Spacecraft Center, 1966. p.117-166.*

#### **Annotation**

##### **Purpose:**

The purpose of this study was to compare the physiological effects of immersion and recumbency. Subjects were immersed in silicone fluid up to neck level for periods up to 30 days.

##### **Method:**

Each subject was immersed to neck level 24 hours per day for 10 days. Simultaneously 3 subjects were at absolute bed rest (and second study reversed subjects), 8 subjects were at absolute bed rest, 6 subjects rode the short-radius centrifuge (SRC) for a 20-min period four

times a day for 80 min per day per subject. Subjects rode at  $+3.5 - 4 g_z$  at the feet and 2 other subjects performed a step function bioassay ride every other day.

**Results:**

All subjects riding the centrifuge four times per day maintained tilt table tolerance. Changes in acceleration tolerance were seen in deconditioned subjects and it returned toward normal with ambulation.

**Conclusion:**

1. SRC training can largely prevent cardiovascular deconditioning from bed rest.
2. There is a severe loss of  $g$  tolerance in subjects deconditioned with bed rest.

**88. White WJ, JW Nyberg, PD White, RH Grimes, LM Finney.**

Biomedical potential of a centrifuge in an orbiting laboratory.

*Santa Monica, CA: Douglas Aircraft Co. Inc., Los Angeles Air Force Station, CA No. SSD-TDR-64-209, Supplement, 1965. 120p.*

**Authors' abstract**

The results of several studies pertaining to manned orbital laboratories are reported.

The first of these studies concerns the consequence of heart-to-foot acceleration gradients for the measurement of tolerance to positive acceleration. A major finding of this study is that two modifications to the standard bioassay method--a low-intensity central light and one gradual onset of acceleration to blackout--make it possible to measure tolerance in the presence of a 219% heart-to-foot gradient with minimal cardiovascular stress.

The second was a parametric study of the power requirements of a short radius centrifuge. The findings here were (1) empty weight of the centrifuge is 155 lb, (2) peak power consumption is 436 watts, (3) energy consumption during a 7.5-min run at  $4g$  is 5.85 Whr.

The third study is an analysis of the errors resulting from use of the centrifuge to determine body mass. The results of an error reduction study and the experimental apparatus for verifying the two-radius method are presented.

The salient generalizations derived from a series of studies in which bed rest was used as the analog of null gravity are presented.

The results of a pilot study to determine the influence of periodic centrifugation on the physiological disturbances associated with 41 days of bed rest are reported in the fourth study. The investigation was carried out during 20 days of bed rest, and 16 days of bed rest with periodic rides on the centrifuge, followed by 5 days of bed rest, centrifugation, and physical exercise. Major findings of this study were (1) motion sickness is not a problem for the well-trained individual when exposed to high angular rates of rotation and modest head or limb movements, (2) deterioration produced by recumbency in the ability to tolerate  $90^\circ$  head-up tilt for 20 min was largely alleviated by periodic centrifugation as judged by syncopal episodes, (3) the three subjects receiving  $+4 g_z$  four times each day showed less lability in blood pressure and heart rate during the tilt-table tests than did the two subjects exposed to  $+1 g_z$ .

The fifth study extended the results of the fourth study by increasing the integrated  $g$ -time from 0.5 and 2  $g$ -hour to 3  $g$ -hour, added approximately 700 kcal of exercise, and distributed the rides over a 24-hour period as contrasted with the 8-hour schedule of the fourth study. A maintenance group of three subjects began riding the centrifuge on the first day of bed rest and rode every day for 13 days. A therapy group of three subjects started riding the centrifuge after 17 days of bed rest and rode periodically for 6 days. A control group of four subjects was transported to and from the centrifuge, but was not rotated. The major finding of this study was that the use of periodic centrifugation and exercise during bed rest tended to prevent deterioration, in the maintenance group, of the mechanisms essential for circulatory control on the tilt table. The effects of centrifugation were indicated by lack of syncope in the maintenance group as compared with three cases of syncope in the noncentrifuged group. The effects of exercise were indicated by heart rate responses during tilt.

As a result of these studies, the potential of the short-radius centrifuge is presented and recommendations for future research are



made; and the impact on future missions is examined.

- 89. Wiegman JF, LP Krock, RR Burton, EM Forster.**  
Anaerobic power testing and +Gz endurance.  
*Aviation, Space, and Environmental Medicine* 60:512, 1989. (Abstract).

**Authors' Abstract**

*Introduction:*

Performance of the L-1 and M-1 straining maneuvers, used during high sustained +Gz, has been described as anaerobic work. Therefore, the present study examines the relationship between anaerobic abilities and +Gz endurance.

*Methods:*

The Wingate cycle ergometer test (WAT) was employed to assess upper and lower body capacity for short-term exhaustive exercise in 8 subjects. Performance indices (measured 3 times) include: peak power for a 5-sec period; 30-sec mean power (MP, an index of anaerobic capacity); and percent fatigue. Acceleration was measured by duration in seconds, on 2 occasions, for a simulated aerial combat maneuver (SACM) profile which alternates 4.5-7 G (15 sec each) until exhaustion. Heart rate was collected online and blood lactates sampled at rest and 3, 6 and 8 min post-WAT and post-SACM.

*Results:*

SACM duration is not significantly correlated with WAT power outputs or blood lactates post-SACM in five subjects tested thus far. However, a correlation coefficient exists between SACM time and highest observed blood lactates following the lower body WAT ( $r = .93$ ). The 2 subjects with the highest single SACM times (391 sec), exhibit contrasting lower body WAT MPs of 495 and 825 W; max heart rates during SACM of 158 and 178 bpm; and peak blood lactates post-SACM of 3.61 and 5.91 mmol/L, respectively.

*Conclusions:*

Some individuals may work at a submaximal intensity, not associated with anaerobic metabolism, during the 4.5-7 G SACM. The role of anaerobic power in +Gz endurance should be further evaluated in a

multifactorial approach which considers individual +Gz tolerance levels.

- 90. Wood EH, EF Lindberg, CF Code, EJ Baldes.**  
Effect of partial immersion in water on response of healthy men to headward acceleration.  
*Journal of Applied Physiology* 18:1171-1179, 1963.

**Authors' Abstract**

Protection against the effects of headward acceleration afforded by immersion in water has been assayed in the human centrifuge on 15 trained subjects. Immersion in water to the xyphoid afforded an average protection of  $1.1 \pm 0.1$  G for vision and ear opacity and of  $1.6 \pm 0.2$  G for ear pulse and heart rate. Deeper immersion, to the level of the third rib at the sternum increased the protection to  $1.8 \pm 0.1$  G for vision and ear opacity and to  $2.8 \pm 0.2$  G for ear pulse and heart rate. The protection afforded the various physiologic variables increased with the magnitude of acceleration tested. Protection against loss of consciousness may be greater than protection against blackout and is probably similar to the protection afforded the ear pulse and heart rate. The cardiovascular reactions produced by headward acceleration are qualitatively similar with and without water immersion. This finding does not support the concept that impediment to venous return is the primary determinant of man's tolerance to headward acceleration. Visual symptoms occurred at greater amplitudes of ear pulse, and presumably also at greater blood pressures at head level, during water immersion than during control runs.

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Use of short-arm centrifuge to prevent deconditioning when immersed in water (according to H-reflex).  
*Kosmicheskaya Biologiya i Aviakosmicheskaya Meditsina* 13:78-79, 1979.

**Author's Abstract**

A study was made of the possibility of using periodic rotation on a short-arm centrifuge (SAC) as a means of preventing the adverse effects of immersion.

Each subject was submitted to +3Gz after pure immersion and immersion combined with periodic rotation on a SAC, where accelerations of +0.8 Gz, +1.2Gz or 1.6 Gz were generated for 60 min twice a day (first series) and for 40 min 3 times a day (second series).

In 76% of the cases there was early recovery of H-reflex amplitude (1<sup>st</sup> - 3d min of aftereffect) with exposure to +3 Gz after immersion combined with SAC when using G forces of +1.2 Gz for 40 min 3 times a day, and 62% for +1.6 Gz for 60 min twice a day.

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**Author Index**  
(numbers refer to abstract number)

Akhrem-Akhremovich RM: 35  
Aleksandrova EA: 72  
Andersen HT: 3  
Andreyeva VG: 37  
Annis J: 71  
Antonutto G: 1  
Armbruster R: 26  
Asyamolov BF: 2, 40  
Augerson WS: 5

Backhausen F: 42,  
Baldes EJ: 90  
Balldin UI: 3, 4, 68, 69, 77  
Baranova BP: 54  
Beckman MC: 5  
Benevolenskaya TV: 60  
Benson VG: 5  
Bernauer EM: 14, 15, 16, 26, 27, 28  
Bjurstedt H: 6  
Bodarenko RA: 2  
Boglevskaya NM: 54  
Boykova OI: 60  
Brock PJ: 24, 25  
Brüner H: 42, 44, 45, 46, 47  
Brunjes S: 59  
Bulbulian R: 7  
Burton RR: 12, 14, 15, 16, 89

Chambers RM: 5  
Chase GA: 8  
Chelnokova NA: 66  
Cherepakhin MA: 9, 35  
Chertovskikh YeA: 54  
Clark WG: 10  
Coburn KR: 5  
Code CF: 90  
Convertino VA: 21, 22, 58  
Cooper KH: 11  
Crisman RP: 12, 63

Davis GL: 27  
DeForest RE: 5  
de Vries H: 59  
di Prampero PE: 1  
Dlusskaya IG: 13  
Dobronravova NN: 61  
Dolkas D: 71  
Driscoll TB: 55

Eichhorn J: 42, 44  
Elizarov SYu: 2  
Elizondo R: 25  
Ellis S: 39  
Epperson WL: 14, 15 16

Finney LM: 85, 86, 88  
Forster EM: 17, 89

Gale RR: 18  
Gardiner IDR: 10  
Gavrilova LN: 18  
Georgiyevskiy VS: 19, 35  
Gogolev KI: 20, 72  
Goldenrath WL: 64  
Goldwater DJ: 21, 22, 58, 70  
Golovkina OL: 23  
Grave C: 8  
Greenleaf JE: 24, 25, 26, 27, 28, 78  
Grigoriev AI: (Gregar'yev AI): 29, 30, 73  
Grimes RH: 88  
Grunbaum BW: 71

Haines RF: 26, 28  
Hannah K: 32  
Henry JP: 59  
Hjort H: 77  
Hoffler GW: 31  
Houghton JO: 32  
Hyatt KH: 33

Jacobson LB: 33  
Johnson PC: 55  
Johnson RL: 31  
Jorgenson H: 10  
Jovy D: 42, 45  
Juhos L: 78

Kakurin LI: 34, 35  
Kaliberdin AV: 2  
Kamenskii YuN: 36, 37  
Katkovskiy BS: 35, 38  
Keil LC: 39  
Khapilov NV: 40  
Khomenko MN: 13  
Khudyakova MA: 41, 73  
Klein KE: 42, 44, 45, 46, 47, 48  
Kokova NI: 49  
Kollias J: 27  
Korotayev MM: 61  
Kotovskaya AR: 35, 50, 51, 52, 53  
Kotov NN: 40  
Kozar MI: 61  
Kozlova VG: 74  
Krauhs JM: 56  
Krikum IS: 18  
Krock LP: 89  
Krupina TN: 54  
Kudrin KA: 74

Kudrova RV: 66  
 Kuklinski P: 48  
 Kuronen P: 4, 68, 69  
 Kuz'min MP: 60  
 Kuznetsov MI: 66  
  
 Leach CS: 55, 56  
 Leverett Jr. SD: 11, 62  
 Lindberg EF: 90  
 Linnarsson D: 1  
 Lobzin PP: 66  
 Lohrbauer LA: 57  
 Ludwig DA: 58  
  
 Matsnev EI: 54  
 McBride DK: 32  
 McCally M: 57  
 McIntyre AK: 10  
 Meehan JP: 59  
 Meyer LG: 63  
 Mikhaylov VM: 19  
 Mikhaylovskiy GP: 60, 61  
 Miller PB: 62  
 Morse JT: 26  
 Mukharlyamov NM: 35  
 Murdoch DM: 63  
 Myhre K: 3  
  
 Newsom BD: 64, 71  
 Nyberg JW: 85, 86, 87, 88  
  
 Ovechkin VG: 18  
  
 Pace N: 71  
 Panchenko VS: 2, 40  
 Panferova NYe: 35  
 Parnell MJ: 65, 84  
 Petrova TA: 60  
 Petrovykh VA: 66  
 Petuknov BN: 67  
 Plokhova VG: 2, 74  
 Polese A: 25  
 Popov IG: 66  
 Purakhin YuN: 67  
 Pushkar YuT: 35  
  
 Romanova IA: 66  
 Rosenhamer G: 6  
 Rositano SA: 70  
 Rowell LB: 8  
 Rusko H: 4, 68, 69  
  
 Sagan L: 26  
  
 Sandler H: 21, 26, 28, 33, 56, 58, 64, 70, 71  
 Savilova AA: 60  
 Schlhalkäuser KL: 44  
 Schotte J: 42, 44  
 Sciaraffa D: 24, 25  
 Senkevich YuA: 35  
 Shamrov PG: 35  
 Shilov VM: 61  
 Shubrooks SJ: 57  
 Shul'zhenko, YeB (EB): 30, 36, 37, 41, 72, 73, 74, 80, 81  
 Simpura SF: 35, 51, 52, 53  
 Solov'yeva SN: 60  
 Spence DW: 75  
 Staley RW: 28  
 Stinnett HO: 27  
 Sundberg CJ: 1  
 Suvorov PM: 76  
 Svensson E: 4  
 Syzrantsev YuK: 66  
  
 Terpilovskiy AM: 66  
 Tesch PA: 3, 68, 69, 77  
 Tizul AY: 54  
 Tsiganova NI: 61  
  
 Udalov YuF: 66  
 Ulyatovsiy NV: 2  
 Ustyushin BV: 18  
  
 van Beaumont W: 26, 28, 78  
 Vanyushina YuV: 35  
 Varbaronov RA: 35  
 Vartbaronov RA: 52, 53  
 Vartbaronov RV: 51  
 Vernikos-Danellis J: 56  
 Vil-Vilyams IF: 72, 73, 79, 80, 81  
 Voigt ED: 44, 46  
 Vogt L: 42, 45, 47  
 Voronin LI: 2  
  
 Webb P: 71  
 Wegmann HM: 42, 44, 45, 46, 47, 48  
 Wessel JA: 82  
 Whinnery JE: 17, 65, 83, 84  
 White PD: 85, 86, 87, 88  
 White WJ: 85, 86, 87, 88  
 Wiegman JF: 89  
 Wigertz O: 6  
 Wiley RL: 57  
 Wilhelmsen U: 3  
 Winter WR: 64  
 Wood EH: 90

**Author Index**  
**(numbers refer to abstract number)**

Wolthuis RA: 31

Yakovleva IYa: 60, 61

Yarov AS: 2, 74

Yelkin PA: 18

Yelkina LG: 18

Young HL: 28, 78

Yusken JW: 28

Zborovskaya BI: 91





# **Keyword Index** (numbers refer to abstract number)

- Abdominal muscle training: 3
- Acceleration tolerance: 2, 5, 7, 9, 10, 11, 12, 13, 14, 15, 17, 19, 21, 22, 24, 25, 27, 30, 31, 32, 35, 39, 40, 42, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 60, 61, 62, 64, 65, 67, 70, 71, 72, 73, 74, 75, 76, 78, 80, 82, 87, 88, 90
- Aerobic
  - fitness: 12, 17, 46
  - training: 22, 84
- Age: 56, 58, 70
- Anaerobic power: 89
- Antigravity: 2
- Arterial lactates: 6
- Artificial gravity: 1
- Bed rest: 7, 9, 19, 21, 26, 27, 28, 31, 34, 38, 39, 50, 51, 52, 53, 54, 55, 56, 59, 60, 61, 62, 67, 70, 71, 78, 85, 86, 87, 88
- Blood
  - clotting: 41
  - pressure: 8, 13, 28, 45, 47, 49, 51, 57, 58, 70, 90, 91
  - volume: 13
- Body weight: 28, 58
- Breathing: 36, 37
- Cardiovascular
  - deconditioning: 1
  - response: 17, 50, 52, 60, 62, 65, 71, 73, 80
- Circulation: 19, 40, 60, 80
- Diet: 9, 66
- Diuresis: 5
- Dynamic endurance: 3
- Electrocardiogram: 2
- Electrolyte responses: 25, 27, 29, 30
- Endocrine responses: 25, 56, 71
- Endurance capacity: 11, 48, 65, 68
- Environment cool/hot: 24
- Exercise:
  - anaerobic: 12
  - heat acclimation: 24
  - training: 4, 12, 23, 52, 54, 63
- Fat: 11, 58, 65, 84
- Fitness test: 82
- Fluid:
  - loss: 10
  - retention: 49
- shifts: 27, 29, 30, 73
- supplements: 49
- Flexor muscles of abdomen and hip: 3
- Formed elements: 61
- Gas exchange: 23
- Gauer-Henry reflex: 5
- G-tolerance: 2, 3, 16, 17, 24, 26, 27, 28, 32, 33, 39, 44, 45, 48, 49, 51, 52, 53, 55, 57, 59, 60, 62, 63, 64, 65, 68, 69, 70, 72, 73, 74, 75, 77, 78, 79, 81, 83, 86, 89
- H-reflex: 91
- Head-down tilt: 2
- Heart rate: 4, 6, 8, 11, 13, 28, 44, 45, 47, 48, 49, 51, 53, 57, 62, 70, 71, 73, 74, 79, 80, 81, 82, 84, 85, 87
- Hematocrit: 10
- Human centrifuge: 1, 3, 8, 18, 23, 37, 41
- Hypokinesia: 2, 9, 18, 19, 34, 35, 40, 54, 60, 61, 67, 74, 76
- Hypoventilation: 8
- Hypoxia: 44, 46, 47
- Immersion: 5, 20, 30, 36, 37, 41, 48, 49, 50, 72, 73, 74, 79, 80, 81, 86, 87, 90, 91
- Immunity: 34, 61
- Intra-abdominal pressure: 3
- Isometric training: 3, 26, 68, 69, 75
- Isotonic exercise: 6, 9, 26
- Knee extensor muscles: 3, 77
- Lean body mass: 11
- Lower body negative pressure (LBNP): 31, 33, 48, 56, 71, 76, 85
- Manned space flights: 29
- Maximal peak torque: 3
- Metabolism: 38
- Muscle:
  - endurance: 3, 67, 75
  - strength: 14
- Musculo-skeletal deconditioning: 1
- Myogram: 2
- Nervous system: 54, 64
- Neuromuscular adaptation: 77
- Orthostatic tolerance: 31, 35, 45, 47, 48, 58, 79, 87

Oxygen uptake: 6, 7, 11, 14, 21, 33, 44, 45, 46, 48, 58, 65, 69, 78, 84, 87

Performance capacities: 8, 45, 69

Peripheral intracranial circulation: 18

Photoplethysmography: 2

Physical:

conditioning: 11, 15, 42, 43, 48

training: 7, 24, 45

Plasma:

protein: 10

renin activity: 39

vasopressin: 39

volume: 27, 58, 78, 85

Psychomotor performance: 59

Pulmonary volumes: 5

Rate of perceived exertion (RPE): 4

Rehydration: 28

Renal function: 30

Respiration: 50, 51, 52, 53, 71

Running: 63, 82

Salt supplements: 49

Schneider test: 46

Short-radius centrifuge: 20, 23, 79, 81, 87, 88, 91

Shuttle flight: 21, 22, 33

Simulated aerial combat maneuver: 4, 7, 14, 15, 16, 77

Specific weight training: 16

Static endurance: 3

Strength training: 68, 69, 77

Submaximal intensity: 89

Syncope: 32, 48, 83

Thyroid function: 55

Tilt test: 13, 33, 42, 43, 45, 48, 88

Training: 44, 46

Transcapillary exchange: 20

Treadmill: 8, 69

Valsalva maneuvers: 51

Veloergometer: 79

Vestibular tolerance: 1

Water loading: 13

Weight: 11, 45, 85

Weight lifting: 63, 82

Work:

capacity: 8

load: 6



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